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Journal
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Vol. 248 NOVEMBER, 1949 No. 5

ELECTRONICS—PAST, PRESENT AND FUTURE

BY

W. C. WHITE [1]

The science of electronics is usually thought of as being new, but this is hardly the case. This year, the JOURNAL is celebrating its 123rd year and, of course, this antedates all except the most elemental observations in this science. However, quite a little had been done as long as 50 years ago.

In 1898 the word "electron" had been in print for seven years. The British scientist, J. J. Thomson, had made the first evaluation of the charge on the electron and Thomas A. Edison had received a patent (fourteen years earlier) on the use of a hot-cathode, two-electrode tube for use as a voltage regulator in the Edison central station system that he was developing.

In another branch of what today is considered electronics, a German physicist had established pretty thoroughly the fundamentals of the mercury-arc rectifier as we know it today. In still other branches of the science, the use of alkali metals for sensitive phototubes had been discovered and the cathode-ray oscillograph had been disclosed with its deflection of beams by electric and magnetic fields.

Of course, this is the familiar pattern of most technical developments. The fundamental research and the disclosure resulting from it precede by several years the practical application. An attempt has been made to show this in the charts that accompany this article. For this purpose the field has been divided into six classifications and the fundamental discoveries basic to each part of the field are listed in connection with a time scale. Included also are the development and practical utilization of the basic ideas that were later evolved.

It is of interest to consider further this matter of the time that elapses between the conclusion of a piece of basic research and when the product is generally available.

[1] Electronics Engineer, General Electric Research Laboratory, Schenectady, N. Y.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

RADIO HIGH-VACUUM TUBES

Fundamental Research	Approximate Year Publication	Approximate Year Availability	Development
Loss of electric charge from hot metals (du Fay)	1725		
Year given is for date of publication or announcement	1800		The selected research results at the left laid the foundation for the products listed below with approximate year commercially available.
	1850		
Hot electrodes lose + and − charges at different rates (Guthrie) Conduction in vacuum from a hot cathode (Edison Effect) Word "electron" coined for indivisible unit of electricity (Stoney) Evaluation of charge of electron (J. J. Thomson)			
	1900		
Basic work on thermionic emission of electron (Richardson) Secondary electron emission (Austin and Stark) Electron emission from oxide-coated cathodes (Wehnelt) The grid electrode for control (de Forest)			The Fleming valve wireless detector The de Forest audion
Ductile tungsten (Coolidge) Pure electron discharge in high vacuum (Langmuir and Arnold)	1910		
Diffusion pump for high vacuum (Gaede) High-vacuum condensation pump (Langmuir) Use of getters in electron tubes Additional grid for high amplification (Schottky)			High-vacuum and high-power diodes and triodes
Electron emission from thoriated tungsten (Langmuir)	1920		Broadcast triode transmitting and receiving tubes
A-c heater cathode (Freeman) Metal-to-glass seal for large diameter cylinders (Housekeeper)			
Screen-grid for radio-frequency amplification (Hull and Williams) Demonstration of wave nature of electrons (Davisson and Germer) Secondary emission suppressor grid (Holst and Tellegan)			Screen-grid transmitting tubes Rectifier tubes for a-c receivers A-c operated receiving tubes Screen-grid receiving tube Magnetron (multi-anode oscillator)
Early work on electron microscope (Ruska and Rudenberg) Strain free alloy seals (Scott and Hull) Steel-envelope technique	1930		Pentode

Steel-envelope receiving tube
Beam power tubes

Klystron

1940

Disk-seal triodes

USE OF ELECTRON OR ION BEAMS IN HIGH VACUUM

Fundamental Research	Approximate Year of Publication or Availability	Development
Fluorescence from ion bombardment (Plucker)	1859	
	1860	
	1870	
Beam of electrons in high vacuum and its deflection by magnetic and electric fields (Crookes)		
	1880	
	1890	
Use of ion beam for oscillography (Braun)		
	1900	
Electron emission from oxide-coated cathodes (Wehnelt)		
The grid electrode for control (de Forest)		
	1910	
Pure electron discharge in high vacuum (Langmuir and Arnold)		
		Coolidge high-vacuum X-ray tube
Wave motion theory of electrons (de Broglie)	1920	
	1930	
		General use of cathode-ray tube for oscillography
Early work on electron microscope (Ruska and Rudenberg)		
		Cathode-ray tube for television reception
		Iconoscope camera tube for television
		Cyclotron (custom built only)
		Beam power tubes
		The Orthicon
	1940	One-million-volt industrial X-ray equipments.
		Electron microscope
		20-million-volt induction accelerator
		100-million-volt induction accelerator
		Mass spectrometer
		Electron diffraction instrument
		Phasitron tube for FM transmitters
		Image Orthicon camera tube for television
		Cathode-ray projection tube for television

TUBES SENSITIVE TO LIGHT—PHOTOTUBES

Fundamental Research	Approximate Year Publication	Availability	Development
Photo-emission of electrons from alkali metals (Elster and Geitel)	1890		
	1900		
Secondary electron emission (Austin and Stack) Basic Theory of photoelectric effect (Einstein)			Phototubes available (custom built)
	1920		Sensitive material on an interior electrode Phototubes commonly available at low cost
	1930		
Secondary electron multipliers	1940		Multiplier phototube

COLD-CATHODE DISCHARGE TUBES

Fundamental Research	Approximate Year Publication	Availability	Development
Research on glow discharge in gases (Faraday)	1838		
Fluorescence from ion bombardment (Plucker)			
Argon discovered (Rayleigh and Ramsay) Neon, krypton, xenon discovered (Ramsay) Gas ionization by collision established (J. J. Thomson)	1900		Moore luminous tube lamps in use
Practical process to get the rare gases (Claude) Geiger particle counter devised (Rutherford and Geiger)	1910		Neon lamps introduced by Claude
	1920		Glow-discharge voltage-regulator tubes Grid-glow tube
	1930		
	1940		Geiger-Mueller counter tubes made in quantity

MERCURY POOL CATHODE TUBES

Fundamental Research	Approximate Year of Publication	Development	Approximate Year of Availability
First mercury arc (Way)	1860		
Rectifying effect noted in mercury arc (Jamin)	1880		
Basic work on mercury arc in vacuum (Arons)	1890		
Gas ionization by collision with electrons established (J. J. Thomson)	1900	Mercury-vapor lamp Mercury-vapor pool rectifier in glass	1910
Grid control in mercury-pool tube (Langmuir)	1910	Pumped tank mercury-arc rectifiers	1915
High-vacuum condensation pump (Langmuir)	1915		
Control of arc current by phase of grid voltage (Toulon) Metal-to-glass seal for large diameter cylinders (Housekeeper)	1920		
Large strain free alloy seals (Scott and Hull) The ignitor for mercury arc cathodes (Slepian) Steel-envelope technique	1930	Pumped ignitrons Sealed steel-envelope ignitrons	1930

HOT-CATHODE, GLOW-DISCHARGE TUBES—TWO-THREE-FOUR-ELECTRODES, THYRATRONS

Fundamental Research	Approximate Year of Publication	Availability	Development
Loss of electric charge from hot metals (du Fay)	1725		
	1800		
Research on glow discharge in gases (Faraday)	1850		
Hot electrodes lose + and − charges at different rates (Guthrie) Conduction in vacuum from a hot cathode (Edison Effect)			
Gas ionization by collision with electrons established (J. J. Thomson) Basic work on thermionic emission of electrons (Richardson) Electron emission from oxide-coated cathodes (Wehnelt) The grid electrode for control (de Forest)	1900		
Grid control in mercury-pool tube (Langmuir)	1910		
			Tungar, low-voltage rectifier
Use of getters in electron tubes	1920		
A-c heater cathode (Freeman) Control of arc current by phase of grid voltage (Toulon) Metal-to-glass seal for large diameter cylinders (Housekeeper)			
Screen-grid tube for radio-frequency amplification (Hull and Willlams) Research on hot-cathode glow discharge (Hull)			Hot-cathode mercury-vapor rectifier The thyratron
Large strain free alloy seals (Scott and Hull) Steel-envelope technique	1930		Ultra-violet incandescent lamps Shield-grid thyratron Steel-envelope industrial tubes
			Fluorescent lamps
	1940		

In the case of radio communication, the British scientist, Maxwell, in 1867 enunciated the theory of the transmission of light, heat and radio waves in space. It was 21 years later, and after the death of Maxwell, that Hertz published his paper which confirmed experimentally the theory of Maxwell. After a further lapse of six years, and after the death of Hertz, the Italian engineer, Marconi, transmitted "wireless" messages in 1894. It was about another ten years before there was much actual everyday use of his developments in radio communication. In this example there was a delay of about 35 years between the presentation of a theory and the common use of products based thereon. This was due in part to the lack of organized research and development.

Electronics for radio communication was somewhat more fortunate in this respect. Only about ten years elapsed between the fundamental work of J. J. Thomson on the electron and the fairly common use of the de Forest audion. The really rapid strides in this science took place after 1911, when organized research took up the work. However, as the charts indicate, some phases of what we now consider electronics were slow in getting under way. These charts show very clearly that like many other fields of science many minds working in many lands have contributed to the methods and devices that are now in common use.

It takes a large volume today to cover even the fundamentals of electronics much less its practical applications. However, one simple concept that embraces pretty much the whole field is to consider that, when an electron tube of any sort is incorporated in an electrical circuit, it introduces a gap in that circuit, where the continuous metallic continuity of that circuit is broken, and in its place is substituted a gaseous or vacuum medium across which the electrical current is carried by charged particles. This gap may be only a few thousandths of an inch in length or it may be measured in feet (Fig. 1). The fundamental point, however, is that in this gap useful effects occur and it is possible to affect the flow of electrical current in a number of unique ways. It is these unique methods of current control that, in general, make the electron tube the valuable device that it is today.

Looked at broadly, there are four of these unique features:

1. High-vacuum tubes have ability to interrupt, re-establish or vary the current in this gap at tremendously high frequency, up to tens of billions of cycles per second. Therefore, in comparison with most other electrical devices, an electron tube designed for use at high frequency is independent of frequency through a very wide range.

2. Most electrical devices for the control of current effect that control in a step-by-step manner. An electron tube designed for the purpose does it with a degree of smoothness unrivaled by any other method. It is this characteristic that allows it to reproduce music and speech with such perfect quality.

3. The flow of electric current across the gap which is fundamental to all vacuum tubes can be controlled by means of the application of an extremely small amount of electrical power. In many cases, kilowatts of energy may be accurately controlled from a few watts of controlled power. This phenomenon, of course, is spoken of as amplification.

4. Many electron tubes are efficient rectifiers both for heavy currents and extremely high voltages.

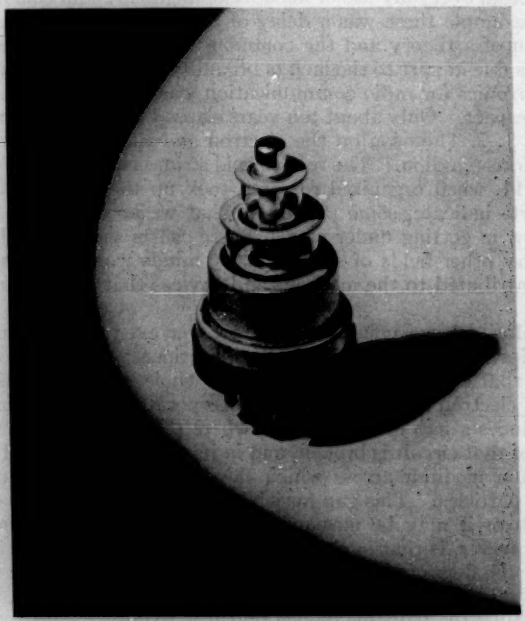

FIG. 1. In every form of electron tube, there are at least two electrodes. The vacuum or gaseous space between these electrodes represents a gap in the circuit. The current control that can be effected in this gap of the physical phenomenon occurring therein is the basic effect which gives electron tubes their unique properties. This gap may be only a few thousandths of an inch in length as in the "lighthouse" type of microwave tube shown above or it may be many feet in length as in the case of a neon sign.

Although there are a number of electrical devices that incorporate one or two of these four unique properties, the electron tube in its more common forms combines several to a remarkable degree.

Electronics is a science of extremes. Electron tubes are in common use that operate at 25 cycles and during the war radar systems were evolved utilizing both transmitting and receiving tubes generating and

responding to about 25 billion cycles. Special tubes are available that act as electrometers for detecting currents of the order of 10^{-16} amperes and others are used for controlling the heavy currents to resistance welders involving the conduction of peak values through the tube of

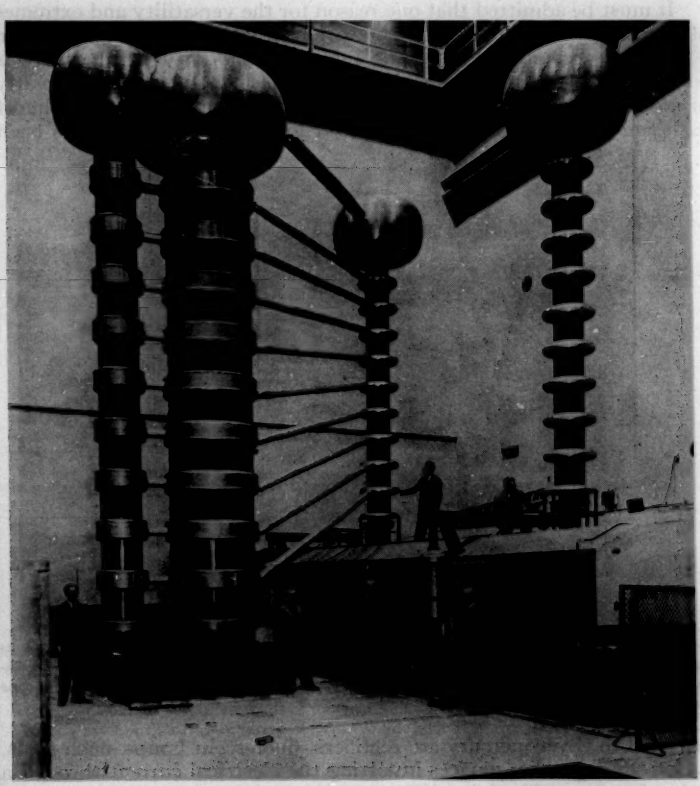

FIG. 2. Electronics is a science of extremes not only in electrical quantities, such as frequency, current and voltage, but also in size. Electron tubes range in size from the tiny ones in a vest-pocket hearing aid to the huge X-ray equipment shown above.

about 10,000 amperes. In communication, sensitive measurement tubes are available that can detect and amplify usefully a few millionths of a volt. At the other extreme, the so-called electron accelerators used for X-ray production and in the studies of nuclear physics operate in the millions of volts.

In physical size there is similar extreme range. Tubes have been built about the size of a kernel of grain. At the other extreme, some forms of tank rectifiers are large enough so that a man could move around inside (Fig. 2).

It must be admitted that one reason for the versatility and extremes of characteristics exhibited by the various kinds of electron tubes is in a measure accounted for by the breadth of activity which today is covered by the term "electronics." This term has broadened greatly in not too many years. Twenty-five years ago, it was applied almost exclusively to high-vacuum tubes used for radio. Today it has been

FIG. 3. Electronics plays an important part in complicated computing devices, such as this differential analyzer, that perform mathematical operations. It can do quickly and without error mathematical work of certain clerical types that otherwise would involve routine mental processes and pencil pushing.

extended to cover mercury-arc rectifiers, fluorescent lamps, neon signs, cyclotrons and other devices involving the electrical current through a vacuum or gas. There is even a tendency to apply the word to devices in which the conduction is through a solid if this conduction has certain unique properties.

Of late, it has become increasingly apparent that electronics is molding a new career for itself. Over the past many years, engineers and particularly electrical engineers have devoted much effort to the creation of labor-saving devices. These have found their places in the home as well as in industry. As a result, much of the hard physical

work formerly done has been eliminated and the human element is now merely the controlling factor. The extent to which this has been done is clearly indicated by the increase of horsepower available to each worker in this country today as compared with not too many years ago.

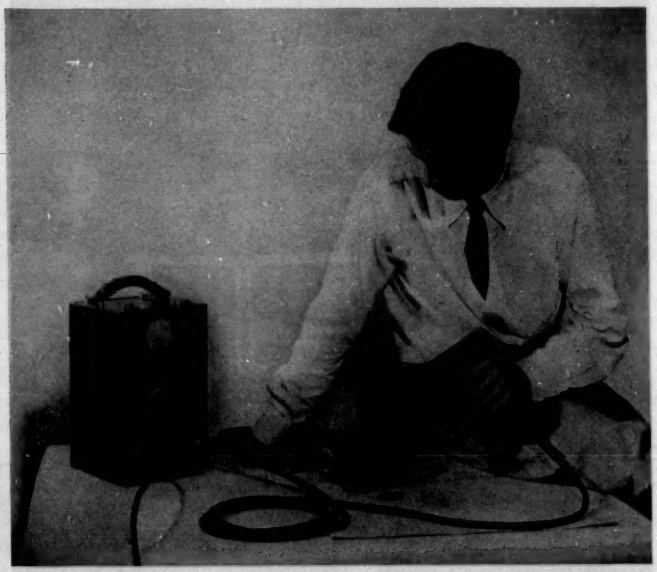

FIG. 4. The microphone, loudspeaker and phototube, each with its associated electronic equipment, simulate the human senses of hearing, speech and vision to a certain extent. Recently this idea has been applied to another one of the senses, that of smell. The device shown above, known as a leak detector, responds to vapors of halogen compounds when present in air to the extent of only a few parts per million. It is finding application as a leak detector which sniffs suspected welds or joints in tanks or piping systems. For a leak test, the system is filled with air under pressure plus the addition of the vapor of some halogen compound, such as freon.

As has been indicated, electronics will probably enter the picture in a somewhat different way. It will be used to simulate, replace or supplement the mental activities of a human being and the accomplishments traceable to his several senses, such as sight, sound and judgment of temperature. This new concept has now been carried even further. One of the most modern electronic devices is the computer by which complicated mathematical operations can be performed (Fig. 3). One of the basic needs in the design of such a computer is a method of storing

up impulses so that they may later be combined. This involves the phenomenon of memory, and here electronics is playing an increasingly important function.

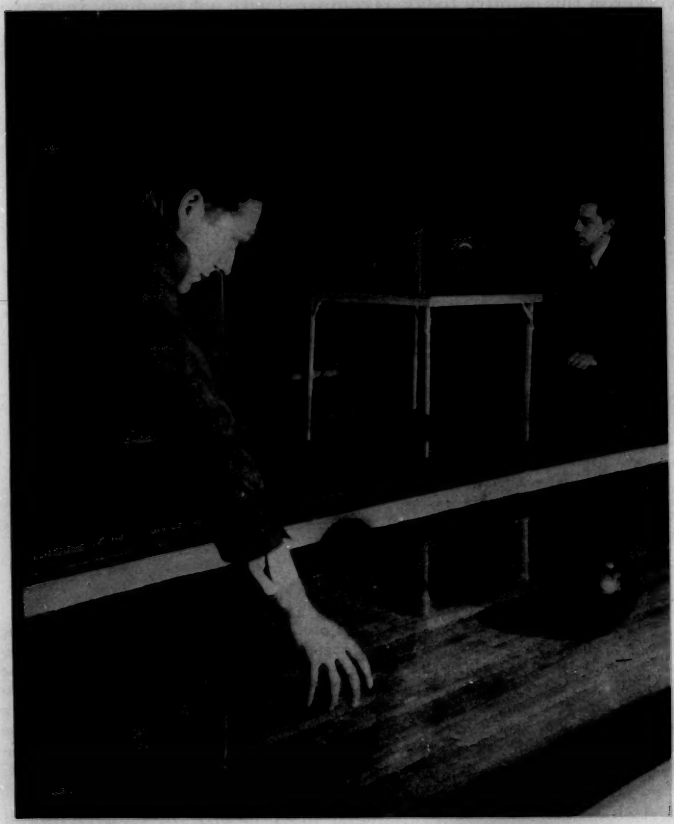

FIG. 5. Electronic devices of many sorts time industrial operations or measure time intervals so short in duration that they are utterly beyond human perception. The radar of World War II involved accurately generating and measuring time intervals of the order of a millionth of a second. In this picture the speed of a bowling ball is determined.

Electronic devices or apparatus in which electronics plays an important part are, as has been stated, used to simulate the common human senses (Fig. 4). Examples of this are the phototube which, like the eye, can respond to varying degrees of illumination; the microphone

with its amplifier that forms an ear, and the loudspeaker with its amplifier that simulates the voice. More recently, an electronic device has been announced with a sense of smell for certain classes of vapors and smokes.

These provide certain of the basic links by means of which the responses of a human being to different stimuli can be fed into an electrical circuit and made to do things that formerly required a muscular response. In other words, we are quite rapidly approaching the point where, by the aid of electronics, we can perform many functions that a human being performs that do not actually require reasoning or judgment. Of course, this process has been going on for years to a certain extent. A familiar example is the automatic home heating plant. Here a thermostat detects the drop of temperature in the room and starts the oil burner operating to raise the temperature to the proper value at which time it is automatically turned off. Formerly, one had first to feel chilly and then respond physically by putting more wood or coal on the fire.

Electronics is greatly extending the sensitivity and scope of even simple temperature-regulating systems. But more important, it is extending our several senses to a marked degree. Examples are modern lie detectors, electrocardiographs and a large number of devices that require timing of an operation in microseconds; many orders of magnitude beyond the human perception of time intervals (Fig. 5).

This idea of a science to simulate many non-muscular human activities is fairly new, but its ramifications and possibilities may well be staggering in their implications.

There is no reason to believe, however, that electronics will permanently be a dominating science. In popular appeal, nucleonics and atomic energy have already stolen from electronics its prominent position in the public's mind. Even technically other devices and methods from time to time invade fields that once were the strongholds for electronic methods. Examples of this are devices in the semi-conductor field, such as crystal diodes and transistors, which threaten to displace small high-vacuum detecting and amplifying tubes in radio broadcast receivers and repeaters for wire telephony. It is true that many physicists consider this new class of device electronic, although it is a far cry from the older and more restricted definition. Mr. D. G. Fink, Editor of the publication *Electronics*, presented a most interesting discussion on this point at the 1948 National Electronics Conference in Chicago, speaking on the subject "Decline and Fall of the Free Electron." He pointed out that all sciences as they pioneered and spread their influence experienced other factors that changed or narrowed their scope.

There is every reason to believe, however, that, when the JOURNAL celebrates it 150th year of publication, electronics will have extended to a wider field and will be functioning in ways in which we now little dream.

Low Voltage Electronic Flash Unit.—Better photographs at lower cost, is the promise of LUMAX Manufacturing Co. in announcing its new 2-way (a.c. and battery) low voltage electronic flash unit.

Electronic flash is growing in popularity because it provides more than 50,000 flashes without changing bulbs, and at practically no cost, once the equipment is acquired. But low voltage, the exclusive LUMAX development has made electronic flash a "must" in producing better pictures because its lengthened duration of flash makes a deeper penetration of the photographic film. While this has always been important in black-and-white, it is critical in color photography which requires ten times longer exposures.

When electronic flash made its bow in the early '40's it was 2500 to 4000 volts with a flash duration of 1/20000 to 1/10000 of a second. It was huge, heavy and costly—definitely not portable. Today's LUMAX units operate at voltages well below 500, flash duration is up to 1/125 of a second, size and weight are one half that of a portable typewriter, and the cost is down to $125 for the 100/watt/second 2-way portable, and as low as $60 for 1-way plug-in units, with self-payment budget plans. The $125 unit is equipped for an additional gun and for phototube wireless synchronizing of any number of units.

Fast, Precise Polarographic Analysis with New Type E Electro-Chemograph.—Designed for rapid, accurate polarographic analyses, a new Leeds & Northrup Type E Electro-Chemograph features one-piece console design incorporating a built-in Speedomax Recorder. Exceptionally flexible and stable, the instrument is convenient for both research and industrial process control laboratories.

Like the previous model of this L&N equipment, the Electro-Chemograph automatically plots diffusion current as a function of voltage. Now, however, the data-taking is done by a Speedomax Microampere Recorder, which provides greater speed of analysis and more complete detail of test results. A typical test run can now be made in about half the previous time.

A full range of variation in test technique is available through a set of controls, all centralized on one panel. Step-by-step instructions for operation, testing and calibration are included on the front of the instrument.

Choice of four degrees of damping enables the user to obtain a record that presents qualitative and quantitative data in the desired detail. Eleven current ranges cover full-scale readings of 1, 2, 3, 5, 7, 10, 15, 20, 30, 50, and 100 microamperes.

There are three polarizing voltage ranges: 0 to -2, -1 to -3, and $+1$ to -1 volts. To cover both anodic and cathodic polarization, any of these ranges can be reversed in polarity. Time to run through a polarizing range is ten minutes. Voltage can be adjusted to ± 4 mv by calibration against an integrally-mounted standard cell.

When it is desirable to obtain several different diffusion current curves on the same chart for intercomparison, the recorder zero can be readily shifted to separate the individual curves.

The equipment is shielded against electrical pick-up, and is not affected by vibration. Normally it is supplied for a-c. operation, but it can be supplied for use with a battery for the polarizer.

APPLICATIONS OF NETWORK THEOREMS IN TRANSIENT ANALYSIS

BY

Y. P. YU[1]

INTRODUCTION

Frequently, the transient solution of a given circuit may be somewhat simplified by the use of a suitable method of attack. Selected methods which have proved themselves to be most useful in simplifying the transient solutions of practical problems will be discussed in this paper. Attention must be called to the fact that each of these methods has one or more limitations which should always be strictly observed. Otherwise serious errors will result. A common limitation is that the values of all passive elements are assumed to be constant. In other words, we are restricted ourselves to constant resistances, inductances, and capacitances. Sometimes this is stated by saying that the passive elements are linear and bilateral.

In this paper, considerable use will be made of Laplace transformation.[2] It is desirable, therefore, to mention a few words about this method. The Laplace transformation of a function $F(t)$ is defined as:

$$L[F(t)] = \int_0^\infty \epsilon^{-st} F(t)dt = f(s);$$

then the inverse Laplace transformation of $f(s)$ is

$$L^{-1}[f(s)] = f(t).$$

For instance,

$$L[\sin wt] = \int_0^\infty \epsilon^{-st} \sin wt\, dt = \frac{w}{s^2 + w^2}$$

and

$$L^{-1}\left[\frac{w}{s^2 + w^2}\right] = \sin wt.$$

Furthermore, the Laplace transformation of the derivative of function $F(t)$ is

$$L[F'(t)] = sf(s) - F(0+)$$

where $F(0+)$ denotes the value of the function $F(t)$ at the instant

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[2] Detailed discussions of Laplace transformation may be found in many standard textbooks, for example: R. V. Churchill, "Modern Operational Mathematics in Engineering," New York, McGraw-Hill, 1944; Gardner and Barnes, "Transients in Linear Systems," John Wiley & Sons, Inc., New York, 1942.

immediately after $t = 0$. It is also important to know the Laplace transformation of the integration of function $F(t)$ which is

$$L\left[\int F(t)dt\right] = L[F^{-1}(t)] = \frac{f(s)}{s} + \frac{F^{-1}(0+)}{s},$$

where

$$F^{-1}(0+) = \int_{-\infty}^{0+} F(t)dt.$$

APPLICATION OF EQUIVALENT CURRENT GENERATOR THEOREM

Frequently, the node method of solution can be advantageously employed in analyzing transient phenomena of electric circuits. The node method which has been discussed in almost every text book concerning electric circuits is essentially a direct application of Kirchhoff's current law, which states that the algebraic sum of all currents directed toward a node or junction, is zero. Current generators are obviously

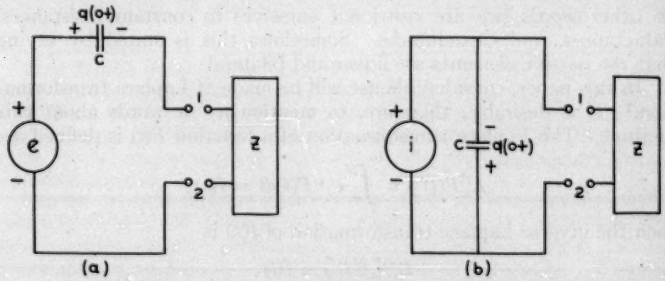

FIG. 1. Conversion of a voltage generator and its series capacitance.

convenient to handle whenever the node method is employed. A statement governing the conversion of a given network into an equivalent network containing a simple current generator shunted with an impedance may be generalized from Norton's theorem and is stated as follows:

A network of generators and passive elements having two terminals is equivalent in its external characteristics to a simple constant-current generator whose generated current is equal to the short-circuit current between the two terminals of the original network and whose shunting impedance has both its transient expression and initial conditions identical to the impedance "looking back" into the two terminals of the original network, measured with all voltage generators (exclusive of internal series impedance) short-circuited and all current generators (exclusive of internal shunt impedance) open circuited.

The above statement may be somewhat clarified by analyzing the following simple cases:

Case I

The conversion of the network to left of terminals 1–2 of Fig. 1(*a*), which contains a voltage generator in series with a condenser C having initial charge $q(0+)$, will be demonstrated in this case. The short circuit current i between terminals 1–2 of Fig. 1(*a*) may be determined from the following equation:

$$e = \frac{1}{C}\int_0^t i\,dt. \tag{1}$$

From Eq. 1, the Laplace transform of i* is found equal to

$$i(s) = Cse(s). \tag{2}$$

The current generator of the equivalent circuit shown in Fig. 1(*b*) will therefore have the Laplace transform of its current equal to $Cse(s)$.

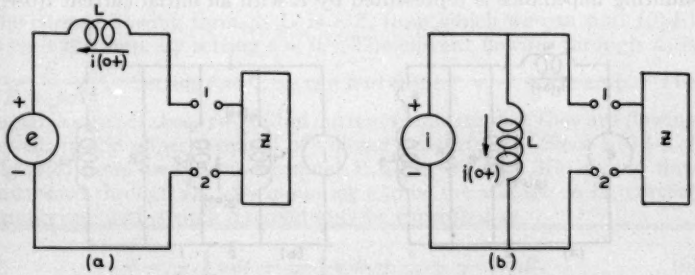

FIG. 2. Conversion of voltage generator and its series inductance.

In order to have the same direction of flow for the short-circuit currents in both networks, the top terminal of the current generator of Fig. 1(*b*) is assigned to be positive. The impedance looking back into terminals 1–2 is represented by condenser C with an initial charge of $q(0+)$. The polarity of the initial charge $q(0+)$ in Fig. 1(*b*) is determined from the original circuit. If the constant-voltage generator of Fig. 1(*a*) is short-circuited, a discharge current will flow out from terminal 2 to impedance Z. Similarly, if the constant-current generator of Fig. 2(*b*) is open-circuited, an equal discharge current should flow out from terminal 2 to impedance Z. Therefore the lower plate of condenser C in Fig. 1(*b*) is positive as far as the initial condition is concerned.

* It is noted that a constant is not the Laplace transform of any actual function. Instead it is the limit of the transform of a step function which is zero except when $t = 0$ at which the function is infinite. Such a function is called Dirac delta function. In case that a battery with potential E is employed for the voltage generator of Fig. 1(a), Eq. 2 becomes $i(s) = CS\left(\frac{E}{S}\right) = CE$. Here CE, a constant, is the limit of the transform of a step function i which is zero except when $t = 0$, the switch is being closed, at this instant the current i is infinite.

Case II

Let the network to the left of terminals 1–2 of Fig. 2(*a*) have a voltage generator and an inductance coil in series. The initial current of the inductance coil is $i(0+)$. Then the equivalent constant-current generator will have its current equal to

$$i = \frac{1}{L}\int_0^t e\,dt. \tag{3}$$

The Laplace transform of i is

$$i(s) = \frac{e(s)}{sL}. \tag{4}$$

The polarity of i, shown in Fig. 2(*b*), should be identical to that of the short-circuit current between terminals 1–2 of the original circuit. The shunting impedance is represented by L with an initial current $i(0+)$.

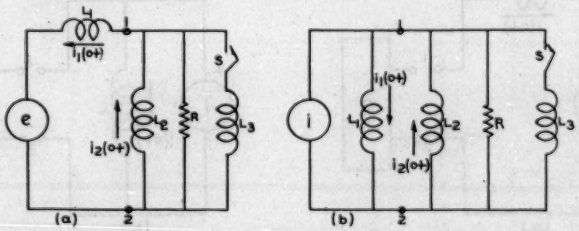

FIG. 3. Illustrating the conversion of a sinusoidal voltage generator into a current generator. $e = E_m \sin wt = 100 \sin 377t$, $L_1 = 0.1h$, $L_2 = 0.2h$, $L_3 = 0.3h$, $R = 100$ ohms.

The polarity of $i(0+)$ is determined in a manner similar to that of the initial charge $q(0+)$ of Fig. 1(*b*). Since the initial current $i(0+)$ of Fig. 2(*a*) flows inward from terminal 1 when its voltage generator is short-circuited, there should be an initial current of equal magnitude and polarity flowing from terminal 1 of Fig. 2(*b*) when its current generator is open-circuited. Thus $i(0+)$ is assigned to flow downward in Fig. 2(*b*).

To illustrate the application of this conversion method the following numerical examples are introduced:

Example 1

Consider a network of inductances and resistances that is energized by an alternating potential. At $t = 0$ a switching operation is performed that will suddenly alter the parameters of the circuit. Figure 3(*a*) is the schematic diagram of this circuit in which switch S is as-

sumed to be closed at $t = 0$. Find the voltage across L_3 at $t = 0.001$ second.

Solution:

The short-circuit current between points 1–2, by Eq. 4:

$$i(s) = \frac{e(s)}{sL_1} = \frac{E_m w}{sL_1(w^2 + s^2)}. \tag{5}$$

The impedance looking back into terminals 1–2 is represented by L, with initial current $i_1(0+)$. Both $i_1(0+)$ and $i_2(0+)$ can be determined from Fig. 3(*a*). Before $t = 0$ the voltage generator e is shunted by a steady-state impedance Z which is

$$Z = jwL_1 + \frac{jwL_2R}{R + jwL_2} = 36.3 + j85.5.$$

The current flowing through L_1 is e/Z, from which we can find $i(0+) = -0.993$ amp. by setting $t = 0$. The current flowing through L_2 is $\frac{e}{Z}\frac{R}{R + jwL_2}$. Setting $t = 0$, we can find $i_2(0+) = -0.835$ amp. The negative signs of these two initial currents indicate that they are flowing inward to the upper terminal of voltage generator e. Since $i_1(0+)$ of Fig. 3(*a*) flows away from terminal 1, $i_1(0+)$ of Fig. 3(*b*) should flow downward through L_1. By assuming v to be the voltage on L_3, current equilibrium with switch S closed may be expressed as

$$i = \frac{1}{L_1}\int v\,dt + \frac{1}{L_2}\int v\,dt + \frac{v}{R} + \frac{1}{L_3}\int v\,dt. \tag{6}$$

The Laplace transform of Eq. 6 is

$$i(s) = \frac{v(s)}{sL_1} + \frac{v^{-1}(0+)}{sL_1} + \frac{v(s)}{sL_2} + \frac{v^{-1}(0+)}{sL_2} + \frac{v(s)}{R} + \frac{v(s)}{sL_3} + \frac{v^{-1}(0+)}{sL_3}, \tag{7}$$

where the boundary values $v^{-1}(0+)/L_1$, $v^{-1}(0+)/L_2$ and $v^{-1}(0+)/L_3$ are initial currents in coils L_1, L_2, and L_3, respectively. Figure 3(*b*) indicates that: (1) the direction of positive current is assumed to be downward; (2) the initial current $v^{-1}(0+)/L_1$ flows downward; and (3) the initial current $v^{-1}(0+)/L_2$ flows upward. Therefore we have $v^{-1}(0+)/L_1 = +0.993$ and $v^{-1}(0+)/L_2 = -0.833$. Obviously $v^{-1}(0+)/L_3$ should be zero. Using the numerical values, the solution of Eq. 7 gives

$$v(s) = \frac{10^2[i(s) - 0.158]}{s + 1833}. \tag{8}$$

Substitute Eq. 5 for $i(s)$,

$$v(s) = \frac{10^5 w}{(s^2 + w^2)(s + 1833)} - \frac{15.8}{s + 1833}. \tag{9}$$

With the aid of equations developed by the use of Laplace transforms, the expression for v can be found as

$$v = 53.5[\sin(wt - 11.6°) + \sin 11.6° \epsilon^{-1833t}] - 15.8\epsilon^{-1833t}.$$

Finally, with $t = 0.001$, the voltage across L_3 is 8.47 volts.

Example 2

Assume that the current in the circuit of Fig. 4(*a*), prior to the closing of switch S, has reached its steady value. Switch S is closed

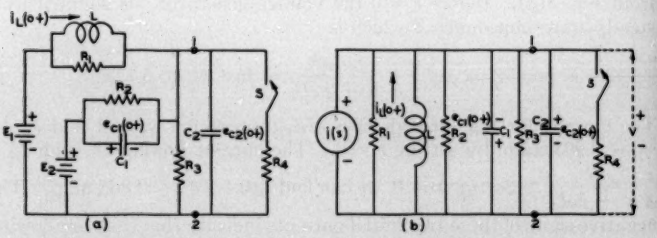

FIG. 4. The conversion of a complex circuit into a simple one-node circuit. $E_1 = 100$, $E_2 = 150$, $L = 1h$, $C_1 = C_2 = 10\ \mu f$, $R_1 = R_2 = R_3 = 1000$ ohms, $R_4 = 50$ ohms.

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at $t = 0$. Find an expression for the voltage across R_4 after the switching action.

Solution:

By observing the circuit of Fig. 4(*a*), the short-circuit current i between terminals 1–2 is found to be the sum of the currents in L_1, R_1, R_2, and C_1, with R_3 shorted. By Eqs. 2 and 4, we can express the Laplace transform of i as

$$i(s) = \frac{E_1}{sR_1} + \frac{E_1}{s^2L_1} + \frac{E_1}{sR_2} + C_1E_2. \tag{10}$$

The impedance looking back into the network at terminals 1–2 with E_1 and E_2 short-circuited is a parallel combination of R_3, C_1, C_2, R_2, R_1, and L_1. The equivalent circuit is shown in Fig. 4(*b*). Initial currents and voltages are determined by analyzing the steady-state conditions of the original circuit with switch S open, that gives $i_L(0+) = 0.05$ amp., $e_{C1}(0+) = 50V$, and $e_{C2}(0+) = 100V$. The polarities of these values are indicated in Fig. 4(*a*). Since $i_L(0+)$ of Fig. 4(*a*) flows toward terminal 1, $i_L(0+)$ should flow upward in Fig. 4(*b*). Voltage $e_{C1}(0+)$ sets terminal 1 negative with respect to terminal 2 in Fig. 4(*a*); thus the upper plate of C_1 is initially negative in Fig. 4(*b*). The equation for

current equilibrium of Fig. 4(*b*) after the close of switch S is

$$L^{-1}i(s) = \frac{V}{R_1} + \frac{1}{L}\int v\,dt + \frac{V}{R_2} + C_1\frac{dV}{dt} + \frac{V}{R_3} + C_2\frac{dV}{dt} + \frac{V}{R_4}, \quad (11)$$

where V is the voltage across R_4. Transforming Eq. 11,

$$i(s) = \frac{v(s)}{R_1} + \frac{v(s)}{Ls} + \frac{v^{-1}(0+)}{Ls} + \frac{v(s)}{R_2} + C_1sv(s) - C_1e_{C1}(0+) + \frac{v(s)}{R_3} + C_2sv(s) - C_2e_{C2}(0+) + \frac{v(s)}{R_4}. \quad (12)$$

The initial current in coil L, namely $v^{-1}(0+)/L$, is equal to -0.05 amp. The negative sign is given because it is directed upward, in opposite with the assigned positive voltage direction. Conversely, $e_{C2}(0+)$ should be equal to $+100$ volts. Using numerical values, a simple expression for $v(s)$ can be found.

$$v(s) = \frac{10^2(s^2 + 150s + 50000)}{s(s + 45.5)(s + 1103)}. \quad (13)$$

With the aid of an equation developed by the use of Laplace transforms, the inverse transform of Eq. 13 becomes

$$v = 100 - 94.3\epsilon^{-45.5t} + 94.3\epsilon^{-1103t}.$$

It is interesting to note the simplicity contributed by employing equivalent current generators in analyzing the above examples.

APPLICATION OF THEVENIN'S THEOREM

Thevenin's theorem is one of the most useful tools in circuit analysis. Although the original statement of this theorem was written for use in steady-state direct-current circuits, its suitability extends to alternating current circuits and transient conditions. A generalized statement of Thevenin's theorem may read as follows:

A network of generators and passive elements having two terminals is equivalent in its external characteristics to a simple constant-voltage generator whose generated voltage is equal to the open-circuit voltage between the two terminals of the original network and whose series impedance has both its transient expression and initial conditions identical to the impedance "looking back" into the two terminals of the original network, measured with all voltage generators (exclusive of internal series impedances) short-circuited and all current generators (exclusive of internal shunt impedances) open-circuited.

The theorem of the preceding section is very similar in every respect to the present one with an exception that the former results in a current generator and an impedance in parallel while the latter results in a voltage generator with the same impedance in series. For this reason, further description of the conversion details seems unnecessary.

Example 3

The circuit shown in Fig. 5(*a*) contains a battery E and the two current generators i_1 and i_2. Before the closing of switch S, the circuit

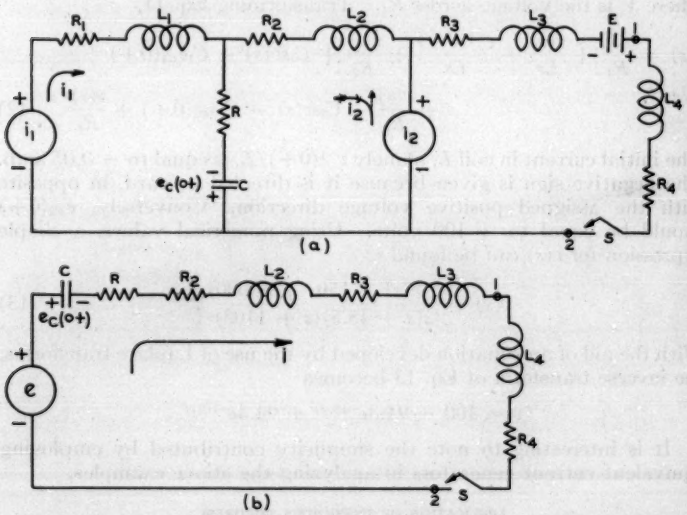

FIG. 5. Illustrating the application of Thevenin's theorem. $i_1 = 1 \sin wt$, $i_2 = 0.5 \sin wt$, $E = 100$, $R = R_1 = R_2 = R_3 = 100$ ohms, $R_4 = 200$ ohms, $L_1 = L_2 = L_3 = L_4 = 0.1h$, $C = 10\ \mu f$, $w = 377$.

is in its steady state condition. At $t = 0$, switch S is closed. Find the current in coil L_4 at $t = 0.001$ sec.

Solution:

To simplify calculations on this circuit, Thevenin's theorem may be used to replace the part of the circuit to the left of terminals 1–2. The open-circuit voltage e at these two terminals is the sum of battery voltage E, voltage drop across R_3L_3 which is zero, voltage drop across R_2L_2 due [3] to the flow of i_2, and voltage drop across RC due [4] to the flow

[3] Let e_{L2} be the voltage drop across L_2, we have $i_2 = \frac{1}{L_2}\int_0^t e_{L2}dt$. Applying Laplace transform to this equation gives $i_2(s) = e_{L2}(s)/sL_2$ or $e_{L2}(s) = L_2 s i_2(s)$. Also see Eq. 4.

[4] Let e_c be the voltage drop on c, then $e_c = \frac{1}{c}\int_0^t (i_1 + i_2)dt$. Transforming this equation, we have $e_c(s) = [i_1(s) + i_2(s)]/sc$. Also see Eq. 2.

of both i_1 and i_2. Therefore, we have

$$e(s) = \frac{E}{S} + R_2 i_2(s) + L_2 s i_2(s) + R[i_1(s) + i_2(s)] + \frac{1}{SC}[i_1(s) + i_2(s)]. \quad (14)$$

The impedance looking back into terminals 1–2 with all current generators open-circuited and all voltage generators short-circuited is a series combination of R_3, L_3, R_2, L_2, R, and C. The equivalent circuit is drawn in Fig. 5(b). Before the switching operation, the current in L_2' is i_2 which is 1 sin wt and the voltage across C is $(i_1 + i_2)/jwc$ which is 398 sin $(wt - 90°)$. Therefore, at $t = 0+$, $i_{L2}(0+) = 0$ and $e_{C2}(0+) = -398$ volts. With this information the polarities of initial values are given in both Figs. 5(a) and 5(b).

The transformed voltage equation for the circuit of Fig. 5(b) is

$$e(s) = \frac{i(s)}{sc} + \frac{i^{-1}(0+)}{sc} + Ri(s) + R_2 i(s) + L_2 s i(s) - L_2 i(0+)$$
$$+ R_3 i(s) + L_3 s i(s) - L_3 i(0+) + L_4 s i(s) - L_4 i(0+) + R_4 i(s). \quad (15)$$

The term $i^{-1}(0+)/C$ is the initial voltage on condenser C and equals $+398$ volts. The positive sign is used because i flows in the direction of increasing this initial potential. Except this term, all other initial values are zero. Employing numerical values, we can find:

$$i(s) = -870\left[\frac{s^2 - 361s - 54300}{(s^2 + w^2)(s + 233)(s + 1433)}\right]. \quad (16)$$

Using a Laplace transform equation, the inverse transform of Eq. 16 becomes

$$i = 0.842\epsilon^{-1433t} - 0.32\epsilon^{-233t} + 0.84 \sin (wt - 38.5°),$$

giving $i = 0.301$ amp. when $t = 0.001$ second.

In using both the equivalent current generator theorem and the Thevenin's theorem, attention must be paid to an important limitation which has been mentioned before and is reiterated here. An equivalent circuit obtained by using either of these methods cannot be employed to calculate either the steady-state or the transient voltage-current relations inside of the portion of the circuit already converted.

APPLICATION OF COMPENSATION THEOREM

In general, it is advantageous to analyze a series circuit with the loop method, and a parallel circuit with the node method. However, experience has shown that complexity would increase in using either of these two methods to attack a predominantly series circuit which contains one or more simple parallel branches, or to attack a predominantly parallel circuit which contains one or more simple series branches. This complexity that is due mainly to the lengthy and awkward mathematical expressions may be greatly reduced by using the compensation

theorem, which is generalized to suit applications in transient conditions as follows:

Any passive element or combination of passive elements—connected in series, parallel, or series-parallel—in a network may be replaced by: (1) a simple voltage generator of zero series impedance whose generated voltage is equal in every respect to the voltage developed across the replaced elements of the original network; or (2) a simple current generator of infinite shunting impedance whose generated current is equal in every respect to the current flowing through the replaced elements of the original network.

Obviously, it is advantageous to adopt the first equivalent for the loop method of solution, and the second equivalent for the node method of solution. The technical questions involved may be made a little clearer by the discussion of the following cases.

Case I

In the network of Fig. 6(*a*), a current i is assumed to flow through

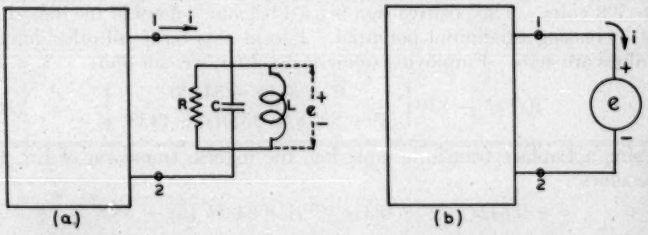

FIG. 6. The establishment of equivalent voltage generator by Compensation theorem.

the parallel combination of R, C, and L. Let it be required to replace this parallel combination with an equivalent voltage generator. If the unknown voltage developed across these parallel elements is represented by the symbol e, we have

$$i = \frac{e}{R} + C\frac{de}{dt} + \frac{1}{L}\int e\,dt. \tag{17}$$

Transforming Eq. 17

$$i(s) = \frac{e(s)}{R} + C[se(s) - e_C(0+)] + \frac{e(s)}{sL} + \frac{e_L^{-1}(0+)}{sL}, \tag{18}$$

where $e_C(0+)$ is the initial voltage across condenser C and $e_L^{-1}(0+)$ is the integral of the initial voltage across L. To evaluate these initial values, it is sometimes convenient to consider the term $Ce_C(0+)$ as the initial charge stored in C and the term $\frac{1}{L}e_L^{-1}(0+)$ as the initial current

flowing through L. Solution of Eq. 18 gives

$$e(s) = \frac{RLsi(s) + RCLse_C(0+) - Re_L^{-1}(0+)}{RCLs^2 + Ls + R} \tag{19}$$

as the Laplace transform of the generated voltage of the equivalent generator in Fig. 6(b). Finally, the top terminal of the equivalent generator is assigned to be positive, making the generated voltage equal in every respect to the voltage drop across the RCL combination of the original network.

The truth of this theorem is readily seen from the standpoint of Kirchhoff's voltage law. The voltage equations, summing up all potential differences in the network, will not be altered when the potential difference between terminals 1–2 of the equivalent network (Fig. 6(b)) is equal in every respect to that of the original network. Therefore, the use of the equivalent voltage generator makes no electrical difference anywhere in the entire network.

Case 2

In the network of Fig. 7(a), the voltage developed across the series combination of R, C, and L is assumed to be e. It is desired to replace

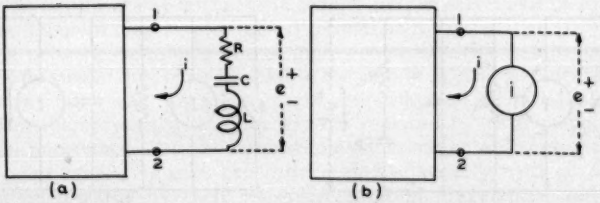

FIG. 7. The establishment of equivalent current generator by Compensation theorem.

this series combination by an equivalent current generator. Let i be the current flowing through these elements.

$$e = Ri + \frac{1}{C}\int i\,dt + L\frac{di}{dt}. \tag{20}$$

The Laplace transform of Eq. 20 is

$$e(s) = Ri(s) + \frac{i(s)}{sC} + \frac{i_C^{-1}(0+)}{sC} + L[si(s) - i_L(0+)], \tag{21}$$

where $i_L(0+)$ is the initial current through L and $i_C^{-1}(0+)$ is the integral of initial current through C. The term $i_C^{-1}(0+)$ may also be considered as the initial charge stored in condenser C. Solving Eq. 21

we have

$$i(s) = \frac{Cse(s) - i^{-1}(0+) + CLsi_L(0+)}{CLs^2 + RCs + 1} \tag{22}$$

as the Laplace transform of the generated current of the equivalent current generator in Fig. 7(*b*). The polarity is so assigned that the currents of both the original and the equivalent networks will be in the same direction.

The identity of these two figures may be proved by employing Kirchhoff's current law. The current equations, summing up all the branch currents in the network, will not be altered if the current flowing through terminals 1–2 of the equivalent network (Fig. 7(*b*)) is equal in every respect to that of the original network. Thus the replacement cannot affect the electrical phenomena anywhere in the entire network.

It is noted that this theorem applies even though the passive elements may neither be linear nor bilateral, because the replacement does not involve any variation in either potential or current anywhere in the network.

Example 4

In this example the use of equivalent current generator is considered. In Fig. 8(*a*), the current generator produces an alternating

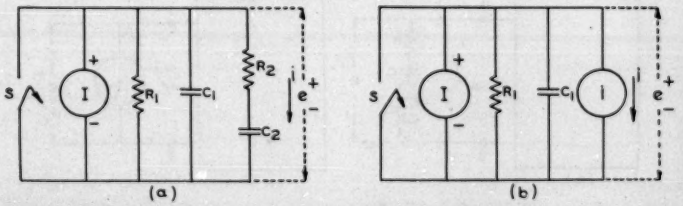

FIG. 8. Simplification by means of equivalent current generator. $I = 10 \cos 377t$, $R_1 = R_2 = 100$ ohms, $C_1 = C_2 = 100$ μf.

current $10 \cos 377t$ amps. Assume that both condensers have zero charge prior to the switching action.

Find the instantaneous voltage developed across condenser C_1 at 0.01 second after the opening of switch S.

Solution:

Employing Eq. 22, the generated current i of the equivalent current generator for R_2 and C_2 may be found. Substitution of $i^{-1}(0+) = 0$, $L = 0$, $C = C_2$, and $R = R_2$ into Eq. 22 gives

$$i(s) = \frac{C_2 se(s)}{R_2 C_2 s + 1}, \tag{23}$$

where $e(s)$ is the Laplace transform of the voltage developed across the passive elements R_1 and C_1. The expression for current equilibrium of the circuit of Fig. 8(b) is

$$I(s) = \frac{e(s)}{R_1} + C_1[se(s) - e(0+)] + i(s), \tag{24}$$

where $e(0+)$ is the initial voltage across C_1 and equal to zero in the present case. Substituting Eq. 23 for $i(s)$, we have

$$e(s) = \frac{I(s)R_1(1 + R_2C_2s)}{(1 + R_1C_1s)(1 + R_2C_2s) + C_2R_1s}. \tag{25}$$

Using numerical values, the expression for $e(s)$ becomes

$$e(s) = \frac{10^5s(100 + s)}{(s^2 + 377^2)(s + 262)(s + 38)}. \tag{26}$$

The inverse transform of Eq. 26 is

$$e = 224 \sin (377t + 25.7°) - 89.3\epsilon^{-262t} - 7.32\epsilon^{-38t}. \tag{27}$$

Therefore the voltage across C_1 will be $-$ 208.5 volts at t = 0.01 second.

APPLICATION OF SUPERPOSITION THEOREM

To suit applications in transient conditions, the statement of superposition theorem may be generalized to read as follows:

In a network containing two or more generators, the instantaneous current flowing at any point is equal to the sum of (1) the instantaneous current at this point due solely to the redistribution of initial energy stored in the network with all generators replaced by their respective internal impedances and (2) the instantaneous currents flowing at the same point caused by each generator acting separately with all other generators replaced by their respective internal impedances and the initial stored energy disregarded.

This theorem is also true when potentials instead of currents are employed for consideration.

Obviously, this theorem is based upon the linear characteristics of the passive elements. When the values of all passive elements in a network are independent of the amount of current through themselves, superposing a second current by an additional generator will not affect the first current which has already been flowing in the network, and vice versa.

Example 5

Square pulses, that have been used extensively for testing the frequency response of electric circuits, provide good examples for the application of superposition theorem since a square pulse may be de-

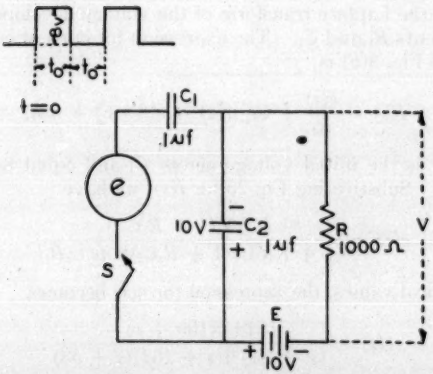

FIG. 9(*a*). Applying a square pulse e to a R–C circuit.

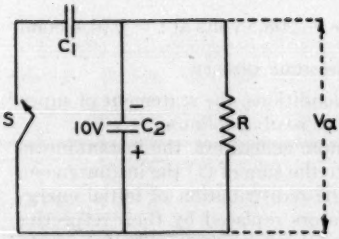

FIG. 9(*b*). Considering the response due to the initially stored energy.

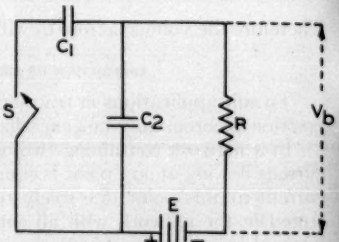

FIG. 9(*c*). Considering the response due to the battery E.

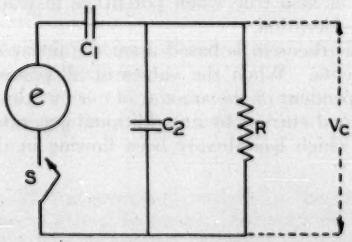

FIG. 9(*d*). Considering the response due to the square pulse e.

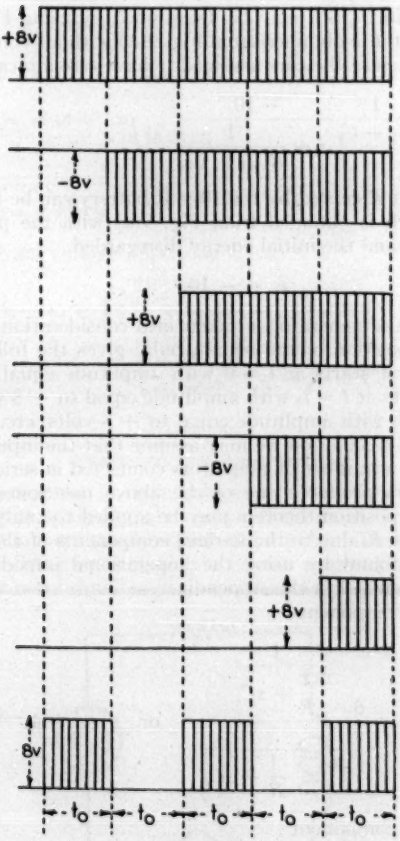

FIG. 9(*e*). Decomposition of the square pulse *e*.

composed into a number of components. In Fig. 9(*a*), the charge on C_2 has reached its steady-state value before $t = 0$, at which switch S is closed. Find an expression for the voltage developed across R after $t = 0$.

Solution:

Before $t = 0$, the voltage on C_1 is zero and on C_2 is 10 volts. After $t = 0$, the voltage developed across R due to the redistribution of the

energy stored in C_2, V_a, may be determined by using Fig. 9(b). This equivalent circuit is obtained from Fig. 9(a) with all voltage generators short-circuited since they are assumed to have zero internal impedances.

$$v_a(s) = \frac{1}{C_1 + C_2} \frac{-10}{s + \dfrac{1}{R(C_1 + C_2)}} \qquad \text{or} \qquad v_a = -5\epsilon^{-5\times10^3 t}.$$

The response at R caused by the 10-volt battery can be found by using Fig. 9(c), which is obtained from Fig. 9(a) with the pulse generator short-circuited and the initial energy disregarded.

$$v_b = -10\epsilon^{-5\times10^3 t}.$$

Finally, the pulse generator is taken into consideration by using Fig. 9(d). Decomposition of the square pulse gives the following components. The first starts at $t = 0$ with amplitude equal to $+8$ volts, the second starts at $t = t_0$ with amplitude equal to -8 volts, the third starts at $t = 2t_0$ with amplitude equal to $+8$ volts, etc., see Fig. 9(e). For the sake of calculation we may assume that the input square pulse is produced by a number of generators connected in series, and each of these generators produces one of the above mentioned components. Then the superposition theorem may be applied to analyze the circuit. The response at R_3 due to the various components of the input square pulse may be found by using the "operational impedance" method that will be discussed in the Appendix.

Due to 1st component

$$v_{c1}(s) = \frac{8}{s} \frac{\dfrac{1}{\dfrac{1}{R} + sC_2}}{\dfrac{1}{sC_1} + \dfrac{1}{\dfrac{1}{R} + sC_2}} \qquad \text{or} \qquad v_{c1} = 4\epsilon^{-5\times10^3 t}.$$

Due to 2nd component

$$v_{c2} = -4\epsilon^{-5\times10^3 (t-t_0)}.$$

Due to 3rd component

$$v_{c3} = 4\epsilon^{-5\times10^3 (t-2t_0)}.$$

Due to nth component

$$v_{cn} = (-1)^{n-1} 4\epsilon^{-5\times10^3 [t-(n-1)t_0]}$$

where n is an integer and equal to $n = (t - t')/t_0$, where $0 < t' < t_0$.

Summation of the above equations gives:

$$v_c = v_{c1} + v_{c2} + v_{c3} + \cdots + v_{cn} = 4\epsilon^{-5\times10^3 t} \sum_{1}^{n} (-1)^{n-1} \epsilon^{5\times10(n-1)t_0}$$

$$= 4\epsilon^{-5\times10^3 t} \frac{1 - \epsilon^{5\times10^3 n t_0}}{1 + \epsilon^{5\times10^3 t_0}}, \quad n \text{ is even.}$$

$$= 4\epsilon^{-5\times10^3 t} \frac{1 + \epsilon^{-5\times10^3 n t_0}}{1 + \epsilon^{-5\times10^3 t_0}}. \quad n \text{ is odd}$$

Therefore the total voltage appearing across R is

$$v = v_a + v_b + v_c = \left(4 \frac{1 - \epsilon^{5\times10^3 n t_0}}{1 + \epsilon^{5\times10^3}} - 15\right) \epsilon^{-5\times10^3 t} \quad n \text{ is even}$$

$$= \left(4 \frac{1 + \epsilon^{5\times10^3 n t_0}}{1 + \epsilon^{5\times10^3}} - 15\right) \epsilon^{-5\times10^3 t}. \quad n \text{ is odd.}$$

APPENDIX

OPERATIONAL IMPEDANCE METHOD

It is known that two or more independent equations must be solved simultaneously in analyzing a series-parallel circuit. The number of independent equations usually equals the number of meshes in the circuit diagram. Thus in analyzing a circuit containing four or more meshes, four or more simultaneous equations are required to be solved.

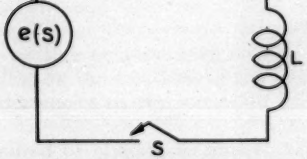

FIG. 10(*a*). Series *RCL* circuit used in connection with the "operational impedance" method.

This mathematical complexity may be eliminated by the use of the "operational impedance" method described here, which is essentially a variant of the "steady-state impedance" method used in elementary alternating-current theory. However, many new difficulties will arise if the circuit to be analyzed is initially active. For this reason, the use of the "operational impedance" method will be restricted here to those circuits which are initially at rest.

In the one-loop *RCL* circuit shown in Fig. 10(*a*) the switch is closed at $t = 0$. Initially, the circuit contains no stored energy. The unknown current $i(s)$ may be found as

$$i(s) = \frac{e(s)}{Z(s)}, \tag{28}$$

where $Z(s) = R + \frac{1}{sC} + sL$ is the total operational impedance of the circuit. The second case to be considered is the one-node circuit of Fig. 10(*b*); the opening of switch S at $t = 0$ allows a known current

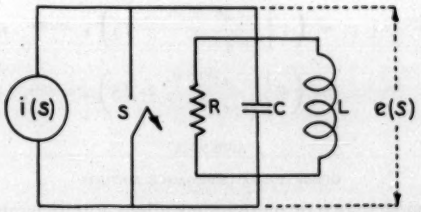

FIG. 10(*b*). Parallel *RCL* circuit used in connection with the "operational impedance" method.

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$i(s)$ to flow to the *RCL* parallel circuit. The initial voltage across C and the initial current through L are both zero. The unknown voltage may be determined as

$$e(s) = i(s)\,Y(s), \tag{29}$$

where $Y(s) = \frac{1}{R} + sC + \frac{1}{sL}$ is the total operational admittance of the circuit.

THE MINIMOTION TYPEWRITER KEYBOARD*

BY

ROY T. GRIFFITH [1]

SYNOPSIS

This paper first points out the defects of the typewriter keyboard now in general use, then describes the design of a keyboard that overcomes these defects and is claimed to afford the greatest attainable ease in writing average English. This is accomplished by determining the optimum key assignments to minimize hard motions (and maximize easy motions), whence the apt name "MINIMOTION."

The present paper concludes with a discussion of the outlook for general adoption of the MINIMOTION keyboard.

Appendices present statistical tabulations of the usage of single and adjacent letters in average English, convenient terminology for analyzing typewriter keyboards in respect to the motions required to write average English, and the comparative results of analyzing several keyboards. These appendices provide sufficient information that the basic statistics and the analysis methods can be applied to any keyboard.

1. INTRODUCTION

The typewriter ranks with the telegraph and the telephone as a medium of commercial communication; as a business machine it ranks with the cash register. Taking a broader view, nearly all the activities of the modern world are directed and recorded by typewriting. The numbers of typewriters in use run into the millions, but more impressive than large numbers is the thought that nearly everything we read: letters, newspapers, magazines, books—whatever the final form—was once typewritten.

The typewriter produces words one letter at a time, but in such a rapid succession that an observer's eye cannot follow the keyboard manipulation. Nevertheless, the operator must direct the motions of the fingers from key to key between each stroke. These motions are easy or hard, depending on the locations of the letters on the keyboard in relation to the adjacencies of the letters in the words being typewritten.

The motions required to operate so important a machine warrant the thorough study reported in this paper.

2. PREVALENCE OF THE QWERT YUIOP KEYBOARD

Nearly all the typewriters now in service have a keyboard bearing the letters of the alphabet arranged as shown in Fig. 1. Conveniently,

* Patent applied for.

[1] Deceased. Formerly, Assistant Engineer in Charge of Transmission, Western Area, Bell Telephone Company of Pennsylvania, Pittsburgh, Pa.

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the top row of letters spells a distinctive and pronouncable name for this keyboard: QWERT YUIOP (kwert-you-ee-opp).

Amazingly, the QWERT YUIOP keyboard of Fig. 1 is almost identical to the keyboard that was devised about 1872 (1)[2] and used on the first commercial typewriter. The original keyboard seems to have survived the early years of typewriter development largely because the pioneer typewriter manufacturer continued to use it while attaining leadership of the new industry. At any rate, the early manufacturers who introduced other keyboards were relatively unsuccessful. By about 1900 the QWERT YUIOP keyboard had become the generally accepted standard, and the "touch system" of operating was steadily gaining acceptance. Since then practically all the typewriters have been made by a few large manufacturers who have never used any but the QWERT YUIOP keyboard. From time to time during these years various "improved" keyboards have been proposed, but most of these have been hardly noticed, and none has

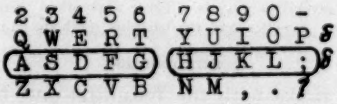

Fig. 1. The QWERT YUIOP Keyboard. The boxes enclose the ten keys that comprise the left and right halves of "Home Row." The two keys marked δ have little usage.

attained important acceptance. Accordingly, the peculiar QWERT YUIOP arrangement has become the very alphabet of the typewriter, and a machine having a different keyboard is quite a curiosity.

Generation after generation of operators has learned to use the QWERT YUIOP keyboard with good speed and accuracy by "touch" alone, with only occasional glances at the keyboard. The skill commonly acquired is such that a competent operator appears to manipulate the keyboard with almost effortless ease.

So the QWERT YUIOP keyboard is as old as the typewriter. It has resisted change for more than 70 years, and it seems to be easy to use. These explain the common presumption that this venerable keyboard must have inherent merit, however obscure. Nevertheless, the QWERT YUIOP keyboard has defects that begin to appear as soon as it is examined critically; finally, the most thorough-going analysis fails to reveal any adaptation to writing English easily.

This paper now proceeds to explain the defects of the QWERT YUIOP keyboard and describe how the MINIMOTION keyboard has been designed to avoid these defects.

3. DEFECTS OF THE QWERT YUIOP KEYBOARD

Five defects of the QWERT YUIOP keyboard are stated and explained below, each in contrast to the possible attainments of a well

[2] The boldface numbers in parentheses refer to the references appended to this paper.

designed keyboard. The statistical percentages apply when writing "average English" (see Part 6) with conventional fingering (see Part 7); the illustrative words are to be tried on a QWERT YUIOP keyboard.

First Defect

On the QWERT YUIOP keyboard 48 per cent of the *motions* to re-position the fingers laterally between consecutive *strokes* are *one-handed motions* rather than the easier *two-handed motions;* on a well designed keyboard one-handed motions can be reduced to 33 per cent, making 67 per cent of the motions two-handed.

One-handed motions are harder than two-handed motions because they afford little opportunity for overlap and anticipation—it is hard to beat a drum rapidly with one stick. A French student of typewriting motions found that one-handed motions consume, on the average, 73 per cent more time than two-handed motions (10). So *dfdfdfdf* or *jkjkjkjk*, done with adjacent fingers of one hand, are harder to execute rapidly than *dkdkdkdk*, which is done two-handed. The words *addressed*, *federated*, and *kiln*, written entirely with one-handed motions, contrast with *sicken*, which is done entirely two-handed.

Second Defect

The QWERT YUIOP keyboard requires *Reaches from Home Row* for 68 per cent of the strokes; on a well designed keyboard these reaches can be reduced to 29 per cent, putting 71 per cent of the strokes in Home Row. (This "Home Row," indicated on Fig. 1, contains the "reference keys" of the "touch system" of typewriting, as explained in part 7 and as diagrammed in Appendix 1.)

In the Home Row of the QWERT YUIOP keyboard only *A*, *S*, *H*, and *L* rank among the ten most common letters; moreover, the unimportant letters *J* and *K* are under the most agile fingers of the right hand.

The *easiest* motions of typewriting are *two-handed motions without reaches from Home Row*, like *dkdkdkdk*. On the QWERT YUIOP keyboard such motions are only 4 per cent and *half* seems to be the only common word that can be written entirely with them; on a well designed keyboard the two-handed motions without reaches can be raised to 34 per cent, and whole sentences can be written with them.

Third Defect

The *hardest* motions of typewriting are *one-handed motions with hurdles over Home Row* (or over the row next above). An extreme example of hurdles is the word *minimum;* other awkward words including several hurdles are *pumpkin* and *execrate*. On the QWERT

YUIOP keyboard 11 per cent of the motions are hurdles; on a well designed keyboard hurdles can be reduced to 1 per cent. (Use of the apt term *hurdle* in this connection seems to be due to Dvorak and his collaborators, (18).

Fourth Defect

The QWERT YUIOP keyboard *overloads the left hand* with 56 per cent of the total strokes; a well designed keyboard has the left hand carry somewhat less than half of the stroking load.

Fifth Defect

The QWERT YUIOP keyboard requires many *awkward fingerings* of one-handed motions yet *loads the fingers inequitably.*

Obviously all typewriter keyboards require repeat strokes on the *same key* to type double letters (as in the work *reef*). However a well designed keyboard should minimize consecutive strokes on different keys done by the *same finger* (as in *parted*). These same-finger fingerings are *S* and *A* because they permit no overlap or anticipation, hence are slow and awkward, like a pianist trying to do a "trill" with one finger. They are specially awkward if they involve a hurdle (as in *secede*). Consecutive strokes that must be done one-handed are somewhat easier if done by *adjacent fingers* or by *remote fingers*, which permit some overlap though much less than two-handed motion. (The word *treated* illustrates a variety of fingerings of one-handed motions.)

On the QWERT YUIOP keyboard about 7 per cent of all the motions are consecutive strokes on different keys done by the same finger, between many of these are hurdles, and several fingers are heavily overloaded; on a well designed keyboard the same-finger fingerings are reduced to about 4 per cent, the same-finger hurdles are almost entirely eliminated, and yet the individual fingers are loaded equitably.

4. ORIGIN OF THE QWERT YUIOP KEYBOARD

The foregoing exposition of the defects of the QWERT YUIOP keyboard calls for an explanation of the origin of the peculiar arrangement of the letters. The origin is obscure and the historians disagree. One writer who considers that the arrangement is not alphabetical says also that it is "nothing like the arrangement of the type in the printer's case (8); another says confidently that the keyboard "follows the idea of the printer's type case" (20). At least three writers (8,18,19) repeat a story that has become traditional: They say that the keyboard was designed to minimize the possibility of conflicting type-bars by keeping well separated those often used on consecutive strokes. This has been accepted without challenge for many years probably because it is plausible and not easy to refute.

The story about the conflicting type-bars is plausible in view of the early mechanical difficulties, but it does not stand up under statistical examination. First defining "close" type-bars as any two having not more than four others intervening on consecutive strokes, application of the statistics of average English reveals that the QWERT YUIOP keyboard actually uses more "close type-bars (26 per cent)

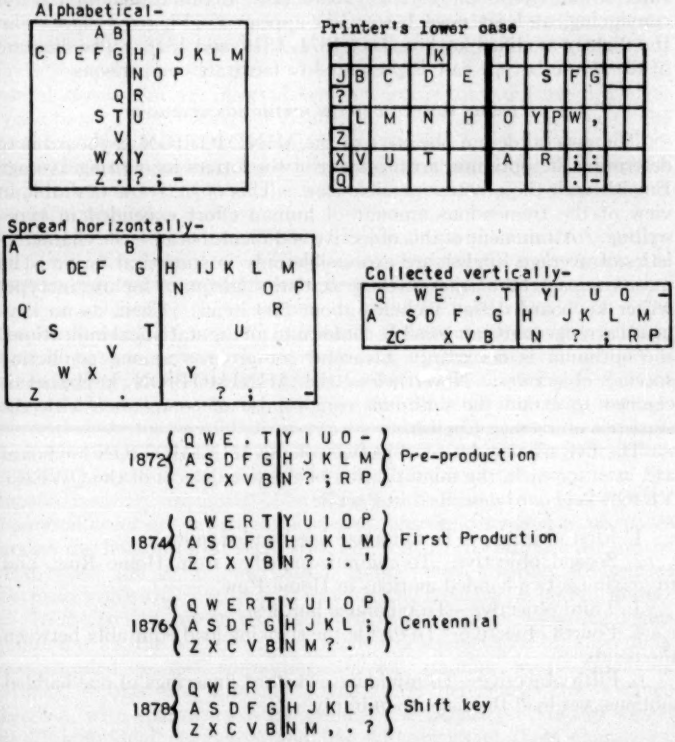
Alphabetical-
A B
C D E F G H I J K L M
N O P
Q R
S T U
V
W X Y
Z . ? ; -
Printer's lower case
K
J B C D E I S F G
?
L M N H O Y P W ,
Z
X V U T A R ; :
Q . -
Spread horizontally-
A B
C DE F G H IJ K L M
N O P
Q R
S T U
V
W X Y
Z . ? ; -
Collected vertically-
Q WE . T YI U O -
A S D F G H J K L M
ZC X V B N ? ; R P
1872 Q W E . T Y I U O -
A S D F G H J K L M
Z C X V B N ? ; R P
Pre-production
1874 Q W E R T Y U I O P
A S D F G H J K L M
Z C X V B N ? ; . '
First Production
1876 Q W E R T Y U I O P
A S D F G H J K L ;
Z X C V B N M ? . '
Centennial
1878 Q W E R T Y U I O P
A S D F G H J K L ;
Z X C V B N M , . ?
Shift key

FIG. 2.

than the RANDOM [3] keyboard (22 per cent) and many more than the MINIMOTION keyboard (14 per cent) as described in Part 8. If the QWERT YUIOP keyboard really had been designed to minimize "close" type-bars, it would certainly have had fewer than the RANDOM keyboard; also it would probably have had fewer one-handed

[3] Described in Part 8.

motions, which would have made it an easier keyboard to use. But if the origin of the QWERT YUIOP keyboard was merely alphabetical, that would not adapt it to write average English easily. Nevertheless, the QWERT YUIOP keyboard does retain vestiges of an alphabetical origin. Figure 2 shows how the letters might have been laid out in eight alphabetical rows, then spread horizontally, finally collected into three rows to yield the 1872 keyboard (1). If this explanation is not convincing, at least none better has appeared. Figure 2 shows also the slightly modified keyboards of 1874, 1876, and 1878. The diagram of the printer's type case is presented to facilitate comparisons.

5. DESIGN OBJECTIVE OF THE MINIMOTION KEYBOARD

The general design objective of the MINIMOTION keyboard is to determine the optimum arrangement of the letters for writing average English with the greatest possible ease. This objective is desirable in view of the tremendous amount of human effort expended in typewriting. Attainment of this objective is difficult because the characteristics of average English are expressible only in statistical form. The most compact tabulation of these statistics adequate for use in typewriter keyboard design includes about 500 items. Then, as no keyboard arrangement can possibly conform to all the statistical indications, the optimum is necessarily a careful compromise among conflicting specific objectives. Nevertheless the MINIMOTION keyboard is claimed to attain the optimum compromise of compliance with the statistics of average English.

The five specific design objectives of the MINIMOTION keyboard are, each for each, the minimization of the five defects of the QWERT YUIOP keyboard described in Part 3:

1. First objective—To minimize one-handed motions.
2. Second objective—To minimize reaches from Home Row, and to maximize two-handed motions in Home Row.
3. Third objective—To minimize hurdles.
4. Fourth objective—To divide the stroking load equitably between the hands.
5. Fifth objective—To minimize awkward fingerings of one-handed motions, yet load the fingers equitably.

6. AVERAGE ENGLISH, STROKES, AND MOTIONS

As typewriters are used to write all kinds of material, the most appropriate basis for keyboard design and analysis is the performance when writing *average English*, comprised of the normal proportions of all kinds of material.

A truly representative sample of average English must contain at least 100,000 running words, so the sample is unwieldy until it is

reduced to statistical form. This is accomplished by first analyzing the sample for the statistical usage of words, then analyzing the words for the statistical usage of single letters and adjacent letters. These analyses must meet particular requirements to yield statistics suitable for application to typewriter keyboard design.

First, the statistics must consider not only *letters*, but also *punctuation marks* and *numerals*—indeed, the major punctuation marks have much higher usage than some letters. A convenient terminology defines *strokes* as the typewriter key operations that mark the paper, thus including punctuation marks and numerals, but excluding the horizontal *spaces* that are inserted between words by operating the letter space bar. Then, taking the number of strokes as the measure of the quantity of typewriting disregards the spaces—properly enough, because the spaces are inserted with negligible effort, and with no appreciable disturbance of the fingers, by either of two agile thumbs that are otherwise idle.

Second, the statistics must consider the usage of consecutive strokes in pairs, conveniently termed *adjacencies*, because these determine the *motions* required to re-position the fingers laterally between consecutive strokes. Directing the execution of these (lateral) motions is really the brain work of typewriting, while the (vertical) strokes involve merely physical effort. This is evident upon consideration that a motorized typewriter almost entirely eliminates the physical effort of strokes but leaves unchanged the mental effort of directing motions. Nevertheless this mental effort can be reduced by designing the keyboard in relation to the usage of adjacencies in average English. Further consideration makes clear that the motion to re-position the fingers between any pair of strokes is independent of the relative temporal order of the two strokes; also that the disregarding of spaces makes the final letter of each word adjacent to the initial letter of the next word (or to a punctuation mark), thus creating adjacencies between words that are treated just like the adjacencies within words.

In the lack of any statistical information satisfying these particular requirements, the author made a statistical study based on a carefully compounded sample containing 107,000 running words involving 510,000 strokes and motions. This study determines, for average English, with customary USA spelling, the usages *per 510,000 strokes* of 37 individual characters and 544 adjacencies of these characters. The final results of this statistical study are attached to the present paper as appendices, described as follows:

Appendix 8 presents the single and adjacent usages per 510,000 strokes for 37 typewriting characters (strokes). These usages are arranged in the form of a square table (37×37), with segregated vowels (vow) and consonants (Con) in alphabetical order, and the non-letter strokes (P + N) in order of usage. The horizontal and

vertical ruled lines follow sub-totals. The vowels are distinctively indicated by lower case letters, the consonants by capital letters, and the numerals by a subsequent sign # (the usages of numerals being assumed concentrated on 0#, 1#, and 2#). In this square table each item is entered twice and is the sum of the usages of the two possible temporal orders of the two component mutually adjacent strokes. For example, the largest entry in the body of the table, appearing in two places, is for the adjacency $TH + HT$, which is the sum of the usages of *TH* (as in *THe*) and *HT* (as in *rigHT*), including adjacencies occurring between words (as in *nexT HigH Tide*). Hence the bottom row and the column at the extreme right, both designated 2Σ, give double the total usage of the single strokes, and the grand total of the individual entries is 1,020,000. The usages of single strokes range from about 60,000 per 510,000 for *e* to 300 per 510,000 for the colon: usages of adjacencies range from about 16,000 per 510,000 for $TH + HT$ to 10 per 510,000 for the smallest entries.

Appendix 6, derived from Appendix 8, presents in columnar form the usages of 37 single strokes, both per 510,000 strokes and per 1000 strokes, arranged in order of usage. The three columns to the right of the usages are Key Group numbers (see Part 7) for the stroke analysis of three typewriter keyboards.

Appendix 7, derived from Appendix 8, presents in columnar form the usages of 544 adjacencies, per 510,000 strokes (and per 1000 strokes for the large items), arranged in order of usage. The three columns to the right of the usages are motion codes (see Part 7) for the motion analysis of three typewriter keyboards. Experience shows that all close comparisons involved in typewriter keyboard design must be made in terms of the usages per 510,000 strokes and must include all the 544 items; however, the final results of such comparisons can usually be displayed best by translating the totals to usages per 1000 strokes.

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7. KEY GROUPS, MOTION CODES, AND FINGERING

Appendix 1 explains a convenient terminology for the classification of strokes and motions. In general, the plan is to number the left and right halves of the four rows of typewriter keys as *Key Groups*. Motions as between any two Key Groups are then designated by two-digit *motion codes* formed from the numbers of the terminal Key Groups, with the smaller number always the first digit. This coding intentionally disregards as insignificant the temporal order of the terminal strokes, and is consistent with the designation of adjacencies in the form $TH + HT$. There are 903 possible different motions among 42 typewriter keys, but only 36 possible different motions among six Key Groups. Hence typewriter keyboards are much more easily analyzed and designed in terms of group-to-group motions than key-to-key

motions. Appendix 1 shows the 36 group-to-group motions by motion codes classified by use of hands and by relative difficulty. The lower left corner of Appendix 1 explains the code letters used to supplement the numerical motion codes to classify the key-to-key motions involved in fingering of one-handed motions.

The light curved lines on the keyboard diagram of Appendix 1 are intended to indicate the *conventional fingering* of a 42-key typewriter keyboard in the "touch system" of typewriting. These light curved lines emanate from the scalloped keys, which are the "reference keys." In "home position" the index fingers touch lightly (or hover over) the keys numbered 14 and 26. The index fingers are required to stroke the two keys in each Key Group nearest the left-right division line. The middle and ring fingers each stroke one key in each Key Group. The little fingers are required to stroke the outer keys and also operate the *CAP.* shift keys off the lower left and right corners of the keyboard. With practice the little fingers can operate these shift keys without getting much out of home position. The letter-space bar is operated by one of the thumbs; the other thumb has nothing to do.

8. THE RANDOM KEYBOARD

The RANDOM keyboard, diagramed and characterized in Appendix 3, was conceived by the author in 1942 as an idealized imaginary keyboard which is the composite of a large number of keyboards each having the letters assigned to its keys perfectly at random. While such a keyboard cannot be realized, its characteristics are completely predictable from probability considerations and are significant when compared to the characteristics of actual keyboards. In particular, the RANDOM keyboard reveals that the QWERT YUIOP keyboard has nearly the characteristics of a random arrangement; in respect to the other keyboards the RANDOM keyboard affords a criterion for appraising the accomplishments of deliberate design as distinguished from the expectations of mere chance.

The RANDOM keyboard has no numeral row of keys but assumes the total stroking load to be uniformly distributed over 30 keys, in three rows of ten keys each, and in six Key Groups of five keys each. Hence, such a keyboard will have one thirtieth of the total stroking load on each key, one sixth in each Key Group, one third in Home Row, and one half on each hand.

Wherever a particular stroke falls on the RANDOM keyboard, the next stroke is equally likely to fall on any one of the 30 keys. Hence, one half the motions will be two-handed; the two-handed motions without reaches from Home Row will be $(2/6)(1/6) = 1/18 =$ about 6 per cent; and the one-handed motions with hurdles over Home Row will be $(4/6)(1/6) = 1/9 =$ about 11 per cent.

More detailed analysis of the RANDOM keyboard yields the

complete distribution of motions by motion codes and the fingering of one-handed motions shown on Appendix 3. Finally an auxiliary study has determined the usage of "close" type-bars as reported in Part 4.

9. THE DVORAK-DEALEY KEYBOARD

The DVORAK–DEALEY "Simplified" Typewriter Keyboard (U.S. Patent 2,040,248 issued in 1936) was designed about 1932 by August Dvorak, a psychologist of the University of Washington who had specialized in time and motion studies of typewriting, and William L. Dealey, another educator (**17,18**). Their keyboard largely avoids the defects of the QWERT YUIOP keyboard, and the several thousand typewriters that have been equipped with DVORAK–DEALEY keyboards have demonstrated excellent performance (**17,18**). The DVORAK–DEALEY keyboard is diagramed and analyzed in Appendix 4 for ready comparison with the other keyboards, and the details of its strokes and motions when writing average English are recorded in one of the columns at the right of Appendices 6 and 7.

10. DESCRIPTION OF THE DESIGN OF THE MINIMOTION KEYBOARD

1. First Objective—To Minimize One-handed Motions

Referring to Appendix 5, the MINIMOTION keyboard diagram shows nine keys in the top row used for numerals. The candidates for the remaining 33 keys are as follows:

26 letters	26 keys
Comma, period, and hyphen, each double	3 keys
Semi-colon/colon, quotation marks, apostrophe, and question mark.	4 keys
	33 keys

These 33 candidates are to be assigned 15 to the left side of the keyboard and 18 to the right side so as to minimize one-handed motions (or maximize two-handed motions). In general, this will be accomplished by assigning to opposite sides of the keyboard the characters that are commonly used adjacently.

The 33 candidates can be assigned as between the left and right sides of the keyboard in more than a billion different ways (15C33 or 18C33). Fortunately all but a few of these possible choices can be eliminated by careful study of the square table of Appendix 8 and classification of the individual characters into three groups which may be conveniently designated as follows:

Alphas—The 5 vowels, the consonant *Y*, and the *punctuation marks*, which are all clearly more commonly adjacent to the major consonants than to one another. The alphas require 13 keys and they are assigned to the left side of the keyboard, primarily to obtain a desirable load for the left hand.

Betas—The 15 consonants *N S R L C M F W P B V X J Q Z*, which are all clearly more commonly adjacent to alphas than to one another. So the betas are assigned to the right side of the keyboard, opposite the alphas.

Gammas—The 5 consonants *T H D G K*, which do not have a clear preponderance of usage adjacent to alphas or betas.

An auxiliary study shows that the left-right assignments of the alphas and betas are correct for maximum two-handed motions no matter how the gammas are assigned. Although the assignments of alphas and betas leave two spare keys on the left and three on the right, arrangements can be made to accommodate any or all of the five gammas on either side of the keyboard. Hence the number of possible choices of gamma assignments is $2^5 = 32$. Each of these 32 choices has been studied in detail for the resulting two-handed motions per 510,000 strokes. The results for the ten best choices and the 32nd choice are shown in Table I.

TABLE I. *Two-handed motions after alpha and beta assignments for 32 different gamma assignments*

Rank of CHOICE	Gamma Assignments LEFT	RIGHT	Two-Handed Motions per 510,000	Two-Handed Motions per 1000
1st	G	THDK	340,452	668
2nd	KG	THD	340,274	667
3rd	H	TDGK	339,690	666
4th*	KH	TDG	339,502	666
5th		THDGK	339,396	666
6th	K	THDG	339,316	666
7th	GH	TDK	338,134	663
8th	KGH	TD	337,848	663
9th	T	HDGK	337,132	661
10th	GT	HDK	336,794	661
	(21 others not shown)			
32nd	KGDHT		293,848	576

* MINIMOTION choice.

The possible gamma assignments result in a rather small range of two-handed motions because the alpha and beta assignments have insured so many of the obtainable two-handed motions. Any of the 32 choices of gamma assignments yields more two-handed motions per 1000 strokes than the QWERT YUIOP keyboard (which has 523), and 20 of the choices yield more than the DVORAK–DEALEY keyboard (which has 653).

As indicated, the fourth choice is considered most satisfactory for the MINIMOTION keyboard. This choice yields 666 two-handed motions per 1000 strokes out of a possible 668 and has other advantages that appear in Parts 10.2 and 10.4.

The two-handed motions of the MINIMOTION keyboard could be increased to 722 per 1000 strokes by providing a second letter *T* on the

left side of the keyboard, but this large gain would be impractical to realize.

The two-handed motions of the several typewriter keyboards per 1000 strokes are:

QWERT YUIOP	523
RANDOM	500
DVORAK–DEALEY	653
MINIMOTION	666

2. Second Objective—To Minimize Reaches From Home Row, and To Maximize Two-handed Motions in Home Row

The MINIMOTION choice of assignments to minimize one-handed motions puts five of the ten most commonly used letters on each side of the keyboard. Hence reaches from Home Row are minimized by assigning *e a o i h* to Key Group #5 and *T N S R L* to Key Group #6. Including the use of the lower case of *L* for the numeral *one*, these assignments insure 709 strokes in Home Row per 1000 keyboard strokes, which is the maximum attainable on ten keys.

The ten letters that have the highest individual usage also have the highest usage of adjacencies as between two groups of five letters each. The MINIMOTION assignments to Key Groups #5 and #6 yield 335 two-handed motions in Home Row per 1000 keyboard strokes, which is the maximum practically attainable. These motions are those coded *56* and described as the *easiest motions* of typewriting. (The motions coded *56* could be increased to 341 per 1000 keyboard strokes by interchanging the assignments of the letters *T* and *H*, but this would decrease the two-handed motions for the whole keyboard from 666 to 661.)

The strokes and two-handed motions in Home Row per 1000 keyboard strokes for the several typewriter keyboards are as follows:

	Strokes	Motions
QWERT YUIOP	316	41
RANDOM	334	56
DVORAK–DEALEY	673	288
MINIMOTION	709	335

3. Third Objective—To Minimize Hurdles

The design to minimize one-handed motions (Part 10.1) has determined the assignments as between the left and right sides of the keyboard; further, the design to minimize reaches and maximize two-handed motions in Home Row (Part 10.2) has determined the assignments to Key Groups #5 and #6. The remaining choices of assignments above and below Home Row are now to be made so as to minimize hurdles, which are described as the *hardest motions* of typewriting. In general, this will be accomplished by assigning to the key groups above and below each half of Home Row characters that are not commonly used adjacently.

First, the low-usage letters *J Q* and *Z* are disposed of by assignment to the three available keys in Key Group #2 at the extreme right of the keyboard. Then there remain ten assignments to be made on the left as between Key Groups #3 and #7, and ten on the right as between Key Groups #4 and #8. The candidates for these twenty assignments are listed in Table II with their individual usages per 1000 strokes.

Evidently the principal problem is to minimize the hurdles coded 37 and 48; those coded 17 and 28 will be few because of the low usage of any characters in Key Groups #1 and #2, also a few strokes in #7 and #8; other hurdles, coded 15 and 26, will also be few and these have already been fixed by the assignments completed in Key Groups #1, #2, #5, and #6.

Considering now the right hand hurdles, the number of possible assignments of the ten letters as between Key Groups #4 and #8 is the combinations of ten items taken five at a time = 252. However, study

TABLE II

On the LEFT as between Key Groups #3 and #7, affecting Hurdles coded 37 and 17		On the RIGHT as between Key Groups #4 and #8, affecting Hurdles coded 48 and 28	
u	27	D	36
y	20	C	28
,	12	M	24
.	11	F	22
–	7	W	20
K	6	G	19
"	4	P	18
'	2	B	15
;:	2	V	10
?	1	X	1
	92		193

of Appendix 8 reveals that few hurdles will result from assigning *D* to Key Group #4, and *V* and *X* to Key Group #8, which reduces the number of possible choices of assignments to 35. Each of these 35 choices has been tested in detail for the resulting hurdles per 510,000 strokes. The results for the five best choices and the 35th choice are shown in Table III. As indicated, the 1st choice was used for the MINIMOTION keyboard.

The left hand hurdles were considered just as thoroughly, but only four choices needed to be tested in detail for hurdles per 510,000 strokes, the range of hurdles was from 2.2 to 3.1 per 1000 strokes, and the choice for the MINIMOTION keyboard tolerates 2.8 left hand hurdles per 1000 strokes to avoid key assignments that appeared otherwise objectionable. (– to #7, ' to u. c.)

In making the assignments to minimize hurdles the strokes in Key Groups #7 and #8 were minimized, as these are a little harder to

reach than Key Groups #3 and #4. Appendix 5 shows the final arrangement of these Key Groups.

The hurdles for both the DVORAK–DEALEY and MINIMOTION keyboards are shown by motion codes in Table IV.

TABLE III. *Right hand hurdles, coded 26, 28, 48*

Rank of Choice	Key Group #4 and #8 Assignments	Hurdles /510,000	Hurdles /1,000
1st*	D C F W G M P B V X	4,092	8.0
2nd	D F W G B C M P V X	4,192	8.2
3rd	D C F W B M G P V X	4,296	8.4
4th	D M F P B C W G V X	4,414	8.6
5th	D M F W P C G B V X	4,473	8.8
(29 others not shown)			
35th	D C W P B M F G V X	5,699	11.2

* MINIMOTION Choice.

TABLE IV. *Hurdles by motion codes*

	DVORAK–DEALEV		MINIMOTION	
Motion Code	Hurdles per 510,000	Hurdles per 1000	Hurdles per 510,000	Hurdles per 1000
15	1,776	3.5	321	0.6
17	70	0.1	0	0.0
37	804	1.6	1,107	2.2
Left	2,650	5.2	1,428	2.8
26	3,754	7.4	1,033	2.0
28	959	1.9	231	0.5
48	5,976	11.7	2,828	5.5
Right	10,689	21.0	4,092	8.0
Total	13,339	26.2	5,520	10.8
		=3%		=1%

The hurdles of the several keyboards per 1000 strokes are as follows:

QWERT YUIOP	113
RANDOM	111
DVORAK–DEALEY	26
MINIMOTION	11

The residual hurdles of the MINIMOTION keyboard mostly occur between words or involve a non-letter character. Some hurdles that occur within words, as in *aDVise*, *eXCept*, *lucKY*, and *suBJect*, are conspicuous but have little usage. Table V lists the ten most common hurdles, which account for nearly half the total.

TABLE V. *Minimotion keyboard, the most common hurdles*

Adjacency	Motion Code	Usage per 510,000
DM + MD	H48R	493
DB	H48R	398
," + ,"	H37A	350
DP + PD	H48A	305
O#T + TO#	H26A	246
FM + MF	H48S	218
FB + BF	H48S	186
GM + MG	H48A	168
Y" + "Y	H37A	166
SO# + O#S	H26S	161
10 above		2691
Others		2829
Total		5520 = 11/1000 = 1 per cent.

4. Fourth Objective—To Divide the Stroking Load Equitably between the Hands

The MINIMOTION choice of assignments to minimize one-handed motions also results in an equitable division of the total stroking load between the hands. The heavier stroking load for the right hand (516 per 1000) seems in line with indications that more than 90 per cent of literate adults are right-handed (15). Some tests (6,12) have found about 10 per cent greater agility for the fingers of the right hand, which suggests that the ideal division of a load of 1000 strokes may be about 475 left and 525 right. At any rate the left-right stroking loads of several keyboards are:

	Left	Right
QWERT YUIOP	561	439
RANDOM	500	500
DVORAK–DEALEY	447	553
MINIMOTION	484	516

5. Fifth Objective—To Minimize Awkward Fingering of One-handed Motions Yet Load the Fingers Equitably

The assignments to minimize one-handed motions, reaches, and hurdles have been by Key Groups, with no regard to the assignments

of the individual keys within each Key Group. The particular assignments internal to the Key Groups determine the fingering of one-handed motions and the division of the stroking load among the fingers. These assignments will now be made to minimize awkward fingerings as well as can be without loading the fingers inequitably.

The several fingerings of one-handed motions are conveniently coded as follows:

Code K—The repeat strokes on the *same key* for double letters, which account for about 30 motions per 1000 strokes;

Code S—The consecutive strokes on different keys done by the *same finger;*

Codes A and R—The consecutive strokes on different keys done by *adjacent fingers* or by *remote fingers*, which account for the remaining one-handed fingerings.

TABLE VI. *Fingering of one-handed motions, per 1000 strokes*

All one-handed motions	QWERT YUIOP	RANDOM	DVORAK-DEALEY	MINI-MOTION
K = Same Key	30	30	30	30
S = Same Finger	73=7%	108=11%	39=4%	41=4%
A = Adjacent Fingers	204	160	139	142
R = Remote Fingers	170	202	139	121
Total one-handed	477	500	347	334
Total two-handed	523	500	653	666
Total Motions	1000	1000	1000	1000
Hurdles only				
HS = Same Finger	26	31	6	3
HA = Adjacent Fingers	54	35	6	4
HR = Remote Fingers	33	45	14	4
Total Hurdles	113	111	26	11

On the left side of the keyboard the number of permutations of assignments that are distinct in respect to fingering are 60 within *each* of the Key Groups #3, #5, and #7, thus making the possible distinct arrangements of the left side of the keyboard = $60^3 = 216{,}000$; on the right side the same number of arrangements results from permutations within Key Groups #4, #6, and #8. However only 12 arrangements of the left side of the keyboard and 36 arrangements of the right side avoid finger loadings that appear inequitable. These 48 arrangements were tested in detail for same-finger fingerings per 510,000 strokes, with hurdles segregated for special consideration. The combination of left-right arrangements chosen for the MINIMOTION keyboard involves 41 same-finger fingerings per 1000 strokes (4 per cent), of which only 3 per 1000 are hurdles. These figures appear in the comparative summary which is Table VI. Analyses of one-handed fingerings per

1000 strokes are in the lower left corner of Appendices 2, 3, 4, and 5; details per 510,000 strokes are in the motion code columns of Appendix 7.

As suggested by Table VII, some of the residual same-finger fingerings of the MINIMOTION keyboard have sufficient usage to be annoying. However some such residuals are inevitable except by making other more serious sacrifices. Finally an auxiliary study indicates that a typewriter keyboard can hardly reduce same-finger fingerings below about 3 per cent no matter what finger loadings are tolerated.

TABLE VII. *Residual same-finger fingerings of the MINIMOTION keyboard*

Adjacency	Motion Code	Usage per 510,000	Usage per 1000
Ho + oH	55S	2,493	5
Yo + oY	35S	1,968	4
DS + SD	46S	1,352	3
BL + LB	68S	1,092	2
RC + CR	46S	979	2
NW + WN	46S	884	2
ue + eu	35S	826	2
,a + a,	35S	796	1
GT + TG	46S	697	1
TP + PT	68S	656	1
10 above		11,743	23
Others		8,948	18
Total		20,691	= 41/1000 = 4 per cent

A guide to equitable loading of individual fingers in recognition of their relative abilities is afforded by experimental findings of Hoke (6) and Riemer (12). Their finger abilities are shown in Table VIII,

TABLE VIII. *Finger abilities and finger loads, per 1000 strokes*

Finger designations	Total Left	L4	L3	L2	L1	R1	R2	R3	R4	Total Right
Hoke-Riemer abilities	475	104	112	126	133	140	139	128	118	525
QWERT YUIOP	561	85	80	182	214	196	88	127	28	439
RANDOM	500	100	100	100	200	200	100	100	100	500
DVORAK–DEALEY	447	83	86	130	148	171	138	138	106	553
MINIMOTION	484	84	92	149	159	192	127	107	90	516

averaged and adjusted to total 1000 for eight fingers, in comparison to the finger loadings of several typewriter keyboards. In relation to the Hoke-Riemer abilities the QWERT YUIOP keyboard overloads the inner fingers of the left hand; however the actual keyboards generally prefer to underload the outer fingers of each hand and let the stronger inner fingers carry the resulting overloads. Comparison of Appendices 4 and 5 shows that both the DVORAK–DEALEY and MINIMOTION keyboards assign such high-usage letters as *S* and *R* to the outer fingers of the right hand in order to attain desirable fingerings.

6. Letter Spacing and Line Spacing

Horizontal spaces between letters, to separate words, are inserted by operating the long space bar at the bottom of the keyboard. The space bar can be operated by either thumb, but assignment of the responsibility to one thumb or the other is desirable to avoid hesitancy. For the MINIMOTION keyboard there is a slight choice in favor of the *left thumb* because an auxiliary study (using statistical details not reproduced here) shows that more words begin and end on the right side of the keyboard than on the left, hence the left hand is less likely to be busy between words than the right hand. Incidentally, the auxiliary study showed that the DVORAK–DEALEY keyboard also should insert spaces with the left thumb, but the QWERT YUIOP keyboard should use the right thumb. These thumb assignments are indicated on the keyboard diagrams of Appendices 2, 4, and 5.

Vertical spaces between lines are inserted incidentally to returning the carriage, usually by a long lever projecting toward the operator from the left end of the carriage. Eventually typewriters will normally be fully motorized, and a suitable keyboard key will control line spacing and carriage return. Accordingly the MINIMOTION keyboard shortens the letter space bar for operation by the left thumb and provides a key convenient to the right thumb labeled *CAR.* and having a "double touch:" when depressed lightly it inserts a line space of pre-set width; when depressed firmly it also returns the carriage. These facilities are shown on the keyboard diagram of Appendix 5.

11. RESULTS OF KEYBOARD ANALYSES

Keyboard diagrams and the results of complete analyses of strokes and motions per 1000 strokes are given for four keyboards in Appendices 2 and 5. These Appendices also show some of the major indices rounded to the nearest whole per cent. Such *percentile ratings* are assembled in Table IX for ready comparison of keyboard performances.

TABLE IX. *Percentile ratings of four typewriter keyboards when writing average English*

	QWERT YUIOP	RANDOM	DVORAK–DEALEY	MINI–MOTION
Strokes by the Right Hand	44	50	55	52
Strokes in Home Row	32	33	67	71
Two-handed motions				
without reaches (Easiest)	4	6	29	34
with reaches (Easy)	48 ⟩52	44 ⟩50	36 ⟩65	33 ⟩67
One-handed motions				
without hurdles (Hard)	37	39	32	32
with hurdles (Hardest)	11 ⟩48	11 ⟩50	3 ⟩35	1 ⟩33
Same-finger fingerings	7	11	4	4

Comparison of these percentile ratings for the strokes and motions of the several keyboards supports the claim that the MINIMOTION keyboard affords the greatest facility for writing average English. This leads to the corollary claim that the MINIMOTION keyboard, being least tiring to the operator, will yield the highest attainable all-day efficiency.

Contrasting with the words used in Part 3 to illustrate the defects of the QWERT YUIOP keyboard, the following sentences have been devised to emphasize the merits of the MINIMOTION keyboard:

1. Done entirely by two-handed motions in Home Row—
   A tenor is a resonator on a rare note.
2. Done entirely by two-handed motions—
   A duck loves a watery locality for a family life.
3. Done entirely in Home Row—
   The senator sits on his leather seat in the national interest.

12. KEYBOARD PERFORMANCE RATINGS

Although similar percentile ratings are properly comparable as among the several keyboards, there is no evident way to combine these various percentile ratings significantly into a single all-inclusive performance rating for each keyboard. This is because the gradings of motions by difficulty are merely relative, and no satisfactory measure of absolute difficulty is available. Ideally, each keyboard should have a single rating, and a superiority of rating should be translatable into savings of time and money.

However, consideration of a keyboard performance rating immediately leads beyond the scope of this paper to a broader need. Operating a typewriter is a complicated human activity that baffles analysis by any ordinary methods. The keyboard is just one of several factors that act and react to influence typewriting performance: the operator, the material, the surroundings, the keyboard, and the machine. Further, all these factors are unknown variables, as illustrated by this extreme example:

> If an official typewriting speed record is set by an operator using a QWERT YUIOP keyboard on a motorized typewriter, who can say how much the performance is due to the skill of the operator, and how much to the feather touch and lightning response of the motorized machine? And who will attempt to estimate how much better the record might have been if the operator had devoted equal effort to developing skill on a MINIMOTION keyboard?

Nevertheless, all the typewriting factors can be evaluated conclusively by systematic collection of many thousands of observations on hundreds of typewriters under actual service conditions. The obser-

vational method of establishing ratings is slow and costly, but the validity of the resulting statistical indications is beyond question. In this connection, the Bell Telephone System has found that the observational method affords the only satisfactory basis for rating the transmission performance of telephones under actual conditions of use (14). Nothing remotely comparable to the telephone observations has been collected for the typewriter. As the telephone and the typewriter share the principal responsibility for commercial communications, similar methods of rating their service performance seem appropriate. The cost of a project to establish sound ratings for typewriter performance will be substantial, but small in comparison to the possible future savings.

The expert operator is characterized by a pace that slows momentarily to accommodate hard motions and speeds through easy motions like an automobile picking the way along a poor road at 10 m.p.h. on the rough spots and 30 m.p.h. on the smooth stretches. For example, chronagraphic investigation by Lahy showed that one-handed motions consumed on the average 73 per cent more time than two-handed motions; investigation by another on operators averaging 130 words per minute found the hardest motions being done at an instantaneous rate of 70 words per minute, while the easiest attained an instantaneous rate exceeding 200 words per minute. Hence a typewriter keyboard that reduces the proportion of hard motions and correspondingly increases the proportion of easy motions inherently produces a greater average speed and output for the same skill and effort; conversely, it requires less time and effort for a fixed output. The data from Lahy and another, plus a few reasonable assumptions, are sufficient to assign an individual speed to each coded motion which immediately enables computation of weighted and relative speeds and times inherent in the several keyboards. The results of an auxiliary study on this plan are as follows:

Performance ratings

Per Cent Ratings of Typewriter Keyboards

For Expert Operators of Equal Skill and Proficiency	Inherent Relative Speed (Fixed Effort)	Inherent Relative Time (Fixed Output)
QWERT YUIOP	101	99
RANDOM	100	100
DVORAK–DEALEY	111	90
MINIMOTION	112	89

13. THE MINIMOTION KEYBOARD

Obviously the cost of manufacturing typewriters is independent of the keyboard arrangement, so the MINIMOTION Keyboard involves no ultimate cost. Conversion of machines having QWERT YUIOP keyboards as part of major reconditioning, would make machines having MINIMOTION Keyboards available on trade-in transactions.

The MINIMOTION Keyboard is not only the easiest to use, but

it should be the easiest to learn. At any rate, the DVORAK–DEALEY Keyboard has amply demonstrated ease of learning (18). Most convincing is the report of tests in 1939 at the University of Chicago School of elementary education, where a group of young beginners using DVORAK–DEALEY keyboards developed proficiency more than twice as fast as a control group using QWERT YUIOP keyboards (18).

Operators already proficient on the QWERT YUIOP keyboard will find learning the MINIMOTION keyboard easier than might be expected. Again the best evidence has been collected by the DVORAK–DEALEY keyboard. The indications are that changing to a MINIMOTION keyboard will reduce the output of a commercial operator not longer than two weeks; thereafter the advantage will continue indefinitely.

So introduction of the minimotion keyboard is no problem at all for new typewriters and new operators, and only a minor problem during conversion. Thereafter the advantage of the MINIMOTION keyboard will continue as long as there is no major change in the usage and spelling of English words.

14. FUTURE OF THE MINIMOTION TYPEWRITER KEYBOARD

As the MINIMOTION keyboard is not now in use, its general acceptance is entirely an expectation for the future. Acceptance will be of three kinds: Scientific, popular, and commercial.

Scientific acceptance is based entirely on excellence of design to meet a need. This paper submits the design of the MINIMOTION keyboard for scientific examination.

Popular acceptance is often determined by prejudice. Generally people will accept a cautious succession of minor improvements but may set up a stubborn wall of prejudice against a major innovation, particularly if it affects a familiar thing and has the taint of reform.

> An extreme example of popular resistance to reform is the experience of the proposals for "Simplified Spelling." Notwithstanding the support of eminent philologists and educators on both sides of the Atlantic (9), these proposals have made little progress in the last 50 years. Accordingly, we in the United States still prefer the spelling *neighbor*, the British continue to insist on *neighbour*, and we both consider *nabor* quite indecent. (Incidentally, as stated in Part 6, the MINIMOTION keyboard is designed to write the "customary USA spelling" represented by *neighbor*.)

The MINIMOTION keyboard is a major innovation that can hardly escape being classed as a reform, yet it does have one important advantage over Simplified Spelling: It affects only the writer, not the reader—using an efficient keyboard does not at all change the appearance of the final typewritten words.

Commercial acceptance is based ultimately on demonstrated savings of time and money, though prejudice is sometimes an initial factor. Convincing demonstration of such savings requires the firm establishment of keyboard performance ratings. Finally, only advertising and salesmanship can bring the obtainable savings effectively to the attention of those who pay for typewriting service. In the long run, the MINIMOTION keyboard will benefit not only those who buy typewriting service but all who have any part in furnishing it.

Whatever the future, the author is gratified to have been able to complete this development that has such great possibilities of reducing the aggregate of typewriting effort.

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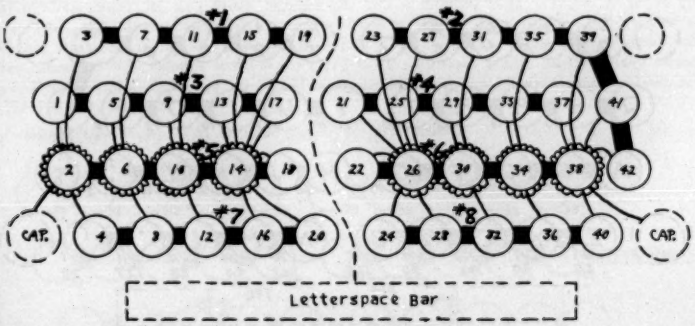
APPENDIX 1. TERMINOLOGY OF KEY GROUPS AND MOTION CODES

Composition and numbering of Key Groups #1 to #8, also key numbers corresponding to typebar numbers 1 to 42:



LEFT Key Groups are odd numbered; RIGHT Key Groups are even numbered. "HOME ROW" is Key Groups #5 and #6 (key 42 being in Key Group #2); "Reference keys" are scalloped and emanating curved lines show fingering, with the index fingers in "home position" on keys 14 and 26.

Key Group plan:

#1	#2
#3	#4
#5	#6
#7	#8

Number of possible different motions: among 42 keys = $\binom{42}{2}$ = (42)(43)/2 = 903; among 8 Key Groups = $\binom{8}{2}$ = (8)(9)/2 = 36, as classified below by motion codes formed from terminal Key Group numbers.

CLASSIFICATION OF MOTIONS by use of hands, by motion codes:

1-handed motions		2-handed motions
Left	Right	
11	22	12
13	24	14 23
H15	H26	16 25
H17	H28	18 27
33	44	34
35	46	36 45
H37	H48	38 47
55	66	→56
57	68	58 67
77	88	78

The antecedent H marks the Hurdles.

Subsequent code letters to show the FINGERING of 1-handed motions:

K = same Key (repeat stroke)
S = Same finger (different keys)
A = Adjacent fingers
R = Remote fingers

CLASSIFICATION OF MOTIONS by relative difficulty, by motion codes:

EASIEST-
2-handed without reaches
→56 only

EASY-
2-handed with reaches
12 14 16 18 23 25 27
34 36 38 45 47 58 67 78

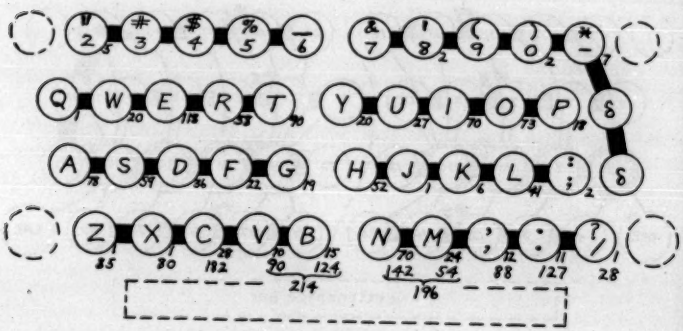
HARD-
1-handed without hurdles
11 13 33 35 55 57 77
22 24 44 46 66 68 88

HARDEST-
1-handed with hurdles
H15 H17 H37
H26 H28 H48

APPENDIX 2. THE *QWERT YUIOP* TYPEWRITER KEYBOARD—1872

Keyboard Diagram and Statistical Distribution of Strokes and Motions

Distribution of strokes by keys and fingers, per 1000 strokes



DISTRIBUTION OF STROKES by Key Groups:

Key Group Plan-		Per 1000 strokes-			% of strokes-		
#1	#2	5	11	16	1	1	2%
#3	#4	287	208	495	28	21	49%
#5	#6	214	102	316	22	10	32%
#7	#8	55	118	173	5	12	17%
		561	439	1000	56%	44%	100%

DISTRIBUTION OF MOTIONS by motion codes, per 1000 strokes:

1-handed motions		2-handed motions	
11= 0	22= 0	12= 0	34=109
13= 3	24= 4	14= 2	36= 85
33= 75	44= 34	16= 1	38= 61
35=123	46= 42	18= 2	45= 88
55= 38	66= 7	23= 7	47= 32
57= 21	68= 9	25= 6	58= 70
77= 1	88= 7	27= 1	67= 10
H15= 3	H26= 2		78= 8
H17= 0	H28= 2	56= 41	
H37= 35	H48= 71		
299	178		523

299 + 523/2 = 561 Left strokes

178 + 523/2 = 439 Right strokes

477 + 523 =1000 Total strokes

FINGERING of 1-handed motions per 1000 strokes:

Same key	30	-	30
Same finger	47	26	73= 7%
Adjacent fingers	150	54	204
Remote fingers	137	33	170
Total 1-handed	364	113	477= 48%

CLASSIFICATION OF MOTIONS by relative difficulty, per 1000 strokes and %:

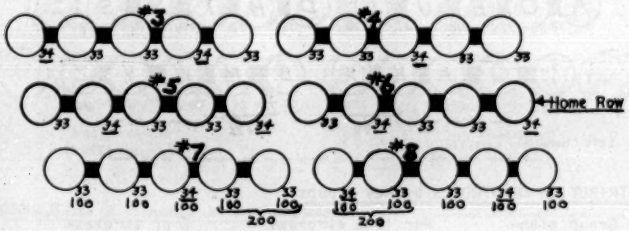
2-handed motions without reaches (EASIEST) . . .	41=	4%
2-handed motions with reaches (EASY).	482=	48%
1-handed motions without hurdles (HARD).	364=	37%
1-handed motions with hurdles (HARDEST) . . .	113=	11%
Total motions=	1000=	100%

APPENDIX 3. THE RANDOM TYPEWRITER KEYBOARD—1942

Keyboard Diagram and Statistical Distributions of Strokes and Motions

Strokes are assumed to fall at random on the 30 keys in 6 Key Groups, hence 1000 strokes and motions distribute as follows: Strokes per key = 1000/30 = 33 + 1/3 = 33 or 34 (to avoid fractions); Strokes per Key Group = 1000/6 = 166 + 2/3 = 167 or 166; Number of different motions among 30 keys = Σ30 = (30) (31)/2 = 465; Number of different motions among 6 Key Groups = Σ6 = (6) (7)/2 = 21. Motions within any one Key Group = 1000/6/6 = 27 + 7/9 = 28 or 27; Motions between any two Key Groups = 1000/3/6 = 55 + 5/9 = 56 or 55.

Distribution of Strokes by keys and fingers, per 1000 strokes



DISTRIBUTION OF STROKES by Key Groups:

Key Group Plan-		Per 1000 strokes-			% of strokes-		
#3	#4	167	166	333	17	16	33%
#5	#6	167	167	334	17	17	34%
#7	#8	166	167	333	16	17	33%
		500	500	1000	50%	50%	100%

DISTRIBUTION OF MOTIONS by motion codes, per 1000 strokes:

1-handed motions		2-handed motions	
33= 28	44= 28		34= 55
55= 28	66= 28		36= 56
77= 27	88= 27		38= 55
35= 56	46= 56		45= 56
57= 56	68= 55		47= 55
H37= 55	H48= 56	56= 56	58= 56
			67= 55
			78= 56
250	250		500

250 + 500/2 = 500 Left strokes
250 + 500/2 = 500 Right strokes
500 + 500 = 1000 Total strokes

FINGERING of 1-handed motions per 1000 strokes:

Same key	30*	≠	30*
Same finger	77	31	108= 11%
Adjacent fingers	125	35	160
Remote fingers	157	45	202
Total 1-handed	389	111	500= 50%

CLASSIFICATION OF MOTIONS by relative difficulty, per 1000 strokes and %:

2-handed motions without reaches (EASIEST) . . . 56= 6%

2-handed motions with reaches (EASY). . . . . 444= 44%

1-handed motions without hurdles (HARD). . . . . 389= 39%

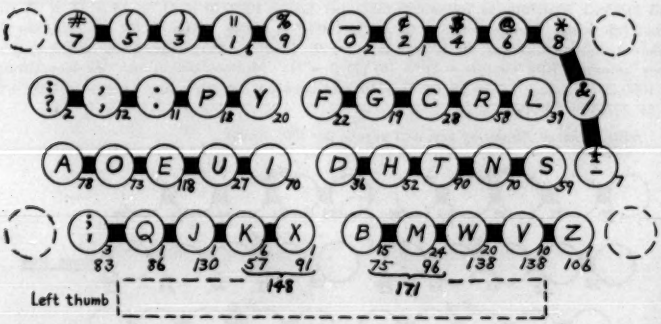
1-handed motions with hurdles (HARDEST) . . . 111= 11%

Total motions= 1000= 100%

*adjusted for average English

APPENDIX 4. THE DVORAK-DEALEY* "SIMPLIFIED" TYPEWRITER KEYBOARD—1932

Keyboard Diagram and Statistical Distributions of Strokes and Motions
Distribution of strokes by keys and fingers, per 1000 strokes



DISTRIBUTION OF STROKES by Key Groups:

Key Group plan-		Per 1000 strokes-			% of strokes-		
#1	#2	6	10	16	1	1	2%
#3	#4	63	166	229	6	17	23%
#5	#6	366	307	673	37	30	67%
#7	#8	12	70	82	1	7	8%
		447	553	1000	45%	55%	100%

DISTRIBUTION OF MOTIONS by motion codes, per 1000 strokes:

1-handed motions			2-handed motions		
11= 0	22= 0		12= 0	34= 23	
13= 2	24= 3		14= 2	36= 33	
33= 5	44= 21		16= 4	38= 11	
35= 44	46= 63		18= 1	45=186	
55= 53	66= 95		23= 1	47= 4	
57= 12	68= 21		25= 6	58= 86	
77= 0	88= 2		27= 0	67= 7	
H15= 3	H26= 7			78= 1	
H17= 0	H28= 2		→56=288		
H37= 2	H48= 12				
121	226			653	

121 + 653/2 = 447 Left strokes
226 + 653/2 = 553 Right strokes
347 + 653 =1000 Total strokes

FINGERING of 1-handed motions per 1000 strokes:

Same key	30	- 30	
Same finger	33	6	39= 4%
Adjacent fingers	133	6	139
Remote fingers	125	14	139
Total 1-handed	321	26	347= 35%

CLASSIFICATION OF MOTIONS by relative difficulty, per 1000 strokes and %:

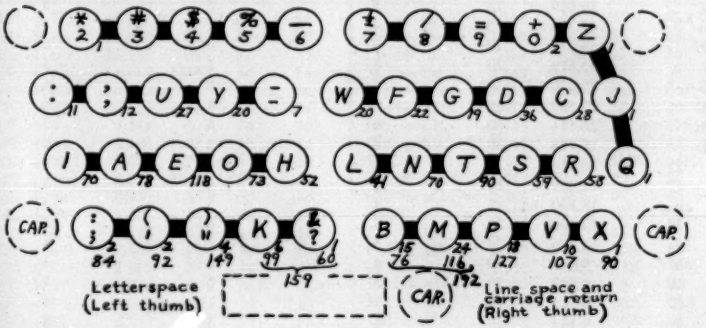
2-handed motions without reaches (EASIEST) . . .	288=	29%
2-handed motions with reaches (EASY).	365=	36%
1-handed motions without hurdles (HARD).	321=	32%
1-handed motions with hurdles (HARDEST) . . .	26=	3%
Total motions=	1000=	100%

*U. S. Patent 2,040,248, issued in 1936.

APPENDIX 5. THE MINIMOTION TYPEWRITER KEYBOARD—1941

Keyboard Diagram and Statistical Distributions of Strokes and Motions

Distribution of strokes by keys and fingers, per 1000 strokes



DISTRIBUTION OF STROKES by Key Groups:

Key Group plan-		Per 1000 strokes-			% of strokes-		
#1	#2	1	5	6	0	1	1%
#3	#4	77	125	202	8	12	20%
#5	#6	391	318	709	39	32	71%
#7	#8	15	68	83	1	7	8%
		484	516	1000	48%	52%	100%

DISTRIBUTION OF MOTIONS by motion codes, per 1000 strokes:

1-handed motions			2-handed motions		
11= 0	22= 0		12= 0	34= 22	
13= 0	24= 1		14= 0	36= 59	
33= 4	44= 8		16= 1	38= 15	
35= 46	46= 68		18= 0	45=132	
55= 87	66= 68		23= 2	47= 5	
57= 11	68= 25		25= 4	58= 78	
77= 0	88= 5		27= 0	67= 11	
H15= 1	H26= 2			78= 2	
H17= 0	H28= 0		56=335		
H37= 2	H48= 6				
151	183				666

151 + 666/2 = 484 Left strokes

183 + 666/2 = 516 Right strokes

334 + 666 =1000 Total strokes

FINGERING of 1-handed motions per 1000 strokes:

Same key	30	=	30	
Same finger	38	3	41=	4%
Adjacent fingers	138	4	142	
Remote fingers	117	4	121	
Total 1-handed	323	11	334=	33%

CLASSIFICATION OF MOTIONS by relative difficulty, per 1000 strokes and %:

2-handed motions without reaches (EASIEST) . . .	335=	34%
2-handed motions with reaches (EASY).	331=	33%
1-handed motions without hurdles (HARD).	323=	32%
1-handed motions with hurdles (HARDEST) . . .	11=	1%
Total motions=	1000=	100%

APPENDIX 6. STATISTICAL USAGE OF 37 SINGLE STROKES IN AVERAGE ENGLISH

Single strokes	Usages per 510,000	Usages per 1000	Typewriter keyboards and Key Group numbers: QWERT YUIOP	DVORAK–DEALEY	MINIMOTION
e	59,888	118	#3	#5	#5
T	46,095	90	3	6	6
a	39,819	78	5	5	5
o	37,366	73	4	5	5
N	35,718	70	8	6	6
i	35,679	70	4	5	5
S	29,980	59	5	6	6
R	29,809	58	3	4	6
H	26,514	52	6	6	5
L	19,788	39	6	4	6
D	18,116	36	#5	#6	#4
C	14,359	28	7	4	4
u	13,890	27	4	5	3
M	12,190	24	8	8	8
F	11,476	22	5	4	4
Y	9,969	20	4	3	3
W	9,947	20	3	8	4
G	9,741	19	5	4	4
P	9,143	18	4	3	8
B	7,448	15	7	8	8
,	6,000	12	#8	#3	#3
.	5,900	11	8	3	3
V	5,053	10	7	8	8
–	3,600	7	2	2	3
K	3,237	6	6	7	7
"	2,200	4	1	1	7
'	1,136	2	2	7	7
0# (zero)	1,000	2	2	2	2
1# (one)	1,000	2	6	1	6
X	798	1	7	7	8
J	651	1	#6	#7	#2
2# (two)	500	1	1	2	1
;	500	1	6	7	7
Q	421	1	3	7	2
?	400	1	8	3	7
Z	369	1	7	8	2
:	300	1	6	3	7
1–37	510,000	1000			

Strokes by Key Groups:	QWERT YUIOP per 510,000	per 1000	DVORAK–DEALEY per 510,000	per 1000	MINIMOTION per 510,000	per 1000
#1	2,700	5	3,200	6	500	1
#3	146,160	287	31,712	63	39,359	77
#5	109,132	214	186,642	366	199,266	391
#7	28,027	55	6,743	12	7,773	15
Left	286,019	561	228,297	447	246,898	484
#2	5,736	11	5,100	10	2,441	5
#4	106,047	208	85,173	166	63,639	125
#6	51,990	102	156,423	307	162,390	318
#8	60,208	118	35,007	70	34,632	68
Right	223,981	439	281,703	553	263,102	516
Total	510,000	1000	510,000	1000	510,000	1000

APPENDIX 7. STATISTICAL USAGE OF 544 ADJACENCIES IN AVERAGE ENGLISH

Adja-cencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
TH + HT	15,952	36	66A	*56*
eR + Re	14,603	33A	45	*56*
He + eH	13,135	36	*56*	55A
iN + Ni	11,052	H48A	*56*	*56*
aN + Na	10,000	58	*56*	*56*
iT + Ti	9,428	34	*56*	*56*
aT + Ta	9,144	35R	*56*	*56*
eN + Ne	9,109	38	*56*	*56*
eT + Te	9,073	33A	*56*	*56*
oN + No	8,918	H48R	*56*	*56*
eS + Se	8,531	35A	*56*	*56*
oR + Ro	7,805	34	45	*56*
aR + Ra	7,483	35R	45	*56*
To + oT	7,144	34	*56*	*56*
eD + De	7,098	35S	*56*	45
ST + TS	7,057	35R	66R	66A
oF + Fo	6,747	45	45	45
iS + Si	6,735	45	*56*	*56*
ND + DN	6,214	58	66R	46R
aS + Sa	5,846	55A	*56*	*56*
Le + eL	5,782	36	45	*56*
Me + eM	5,463	38	58	58
aL + La	5,427	*56*	45	*56*
NT + TN	4,919	38	66A	66A
ea + ae	4,881	35R	55R	55A
Ha + aH	4,770	*56*	*56*	55R
ou + uo	4,737	44R	55R	35A
Ve + eV	4,572	H37A	58	58
Ce + eC	4,509	H37S	45	45
Li + iL	4,501	46A	45	*56*
NG + GN	4,441	58	46A	46A
Ri + iR	4,376	34	45	*56*
RT + TR	4,000	33S	46A	66R
Ca + aC	3,792	57R	45	45
iC + Ci	3,706	47	45	45
Hi + iH	3,642	46A	*56*	55R
Co + oC	3,528	47	45	45
oM + Mo	3,514	H48R	58	58
Be + eB	3,349	H37A	58	58
aD + Da	3,337	55R	*56*	45
So + oS	3,331	45	*56*	*56*
eW + We	3,323	33A	58	45
Ma + aM	3,208	58	58	58
ei + ie	3,118	34	55A	55R
Di + iD	3,085	45	*56*	45
uS + Su	3,056	45	*56*	36
io + oi	2,992	44A	55R	55R
LL	2,871	66K	44K	66K
uR + Ru	2,751	34	45	36
Pe + eP	2,734	34	35A	58
1–50	298,789 = 58.6%			

Adja-cencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
ai + ia	2,712	45	55R	55A
oW + Wo	2,706	34	58	45
Lo + oL	2,567	46S	45	*56*
Mi + iM	2,559	H48A	58	58
NS + SN	2,551	58	66A	66R
uT + Tu	2,518	34	*56*	36
Ho + oH	2,493	46R	*56*	55S
Wa + aW	2,468	35A	58	45
TT	2,329	33K	66K	66K
uN + Nu	2,315	H48S	*56*	36
Ge + eG	2,284	35A	45	45
SS	2,257	55K	66K	66K
Fi + iF	2,226	45	45	45
Po + oP	2,222	44A	35R	58
ee	2,215	33K	55K	55K
Do + oD	2,203	45	*56*	45
RS + SR	2,196	35R	46A	66A
CH + HC	2,174	67	46A	45
TY + YT	2,107	34	36	36
eF + Fe	2,078	35A	45	45
SH + HS	2,050	*56*	66R	*56*
aY + Ya	1,986	45	35R	35R
Yo + oY	1,968	44R	35R	35S
WH + HW	1,958	36	68A	45
Pa + aP	1,937	45	35R	58
eo + oe	1,889	34	55A	55A
LY + YL	1,879	46R	34	36
iG + Gi	1,833	45	45	45
Wi + iW	1,831	34	58	45
iV + Vi	1,803	47	58	58
uL + Lu	1,762	46R	45	36
CT + TC	1,737	H37A	46S	46R
LD + DL	1,721	*56*	46R	46R
NC + CN	1,688	78	46A	46R
PR + RP	1,681	34	34	68R
aV + Va	1,650	57R	58	58
Ga + aG	1,594	55R	45	45
LT + TL	1,587	36	46R	66A
DT + TD	1,561	35A	66A	46A
eY + Ye	1,561	34	35A	35A
.T + T.	1,552	38	36	36
,T + T,	1,538	38	36	36
aB + Ba	1,526	57R	58	58
RD + DR	1,403	35A	46R	46A
Fa + aF	1,403	55R	45	45
RY + YR	1,367	34	34	36
DS + SD	1,352	55A	66R	46S
e. + .e	1,328	38	35S	35R
e, + ,e	1,318	38	35A	35A
Bu + uB	1,314	47	58	38
51–100	+96,957			
1–100	395,746 = 77.6%			

* QWERT YUIOP
** DVORAK–DEALEY
*** MINIMOTION

APPENDIX 7. STATISTICAL USAGE OF 544 ADJACENCIES IN AVERAGE ENGLISH—Continued

Adja-cencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
GH + HG	1,306	*56*	46S	45
GR + RG	1,306	35S	44R	46R
FT + TF	1,300	35S	46A	46A
oo	1,276	44K	55K	55K
FR + RF	1,260	35S	44R	46R
Bo + oB	1,250	47	58	58
PL + LP	1,244	46A	34	68A
SP + PS	1,231	45	36	68A
Ke + eK	1,190	36	57A	57A
Go + oG	1,187	45	45	45
uC + Cu	1,095	47	45	34
BL + LB	1,092	67	H48R	68S
SC + CS	1,064	57A	46R	46A
uP + Pu	1,045	44R	35S	38
S. + .S	1,040	58	36	36
S, + ,S	1,030	58	36	36
YS + SY	1,011	45	36	36
TW + WT	1,006	33R	68S	46A
SW + WS	992	35S	68R	46R
RC + CR	979	H37A	44A	46S
RN + NR	979	38	46S	66R
au + ua	978	45	55R	35A
LS + SL	977	*56*	46S	66R
RM + MR	976	38	H48R	68R
uG + Gu	960	45	45	34
–T + T–	947	23	H26R	36
Pi + iP	942	44R	35S	58
Mu + uM	925	H48S	58	38
oa + ao	908	45	55A	55R
SM + MS	907	58	68R	68R
NW + WN	884	38	68A	46S
BY + YB	883	47	38	38
oV + Vo	827	47	58	58
ue + eu	826	34	55A	35S
e– + –e	810	23	25	35A
.a + a.	805	58	35R	35A
,a + a,	796	58	35A	35S
NY + YN	782	H48S	36	36
MP + PM	775	H48R	38	88A
BR + RB	766	H37S	H48R	68R
aK + Ka	757	*56*	57R	57R
MY + YM	753	H48S	38	38
D. + .D	720	58	36	34
D, + ,D	714	58	36	34
Du + uD	713	45	*56*	34
HR + RH	706	36	46R	*56*
CK + KC	703	67	47	47
TM + MT	698	38	68A	68A
GT + TG	697	35S	46A	46S
.o + o.	695	H48S	35A	35R
101–150	+47,713			
1–150	443,459 = 87.0%			

Adja-cencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
,o + o,	688	H48A	35S	35R
eX + Xe	681	H37A	57A	58
SF + FS	675	55R	46R	46R
TP + PT	656	34	36	68S
FF	650	55K	44K	44K
N. + .N	649	88R	36	36
KN + NK	646	68A	67	67
N, + ,N	644	88A	36	36
SB + BS	636	57R	68R	68R
S– + –S	634	25	H26S	36
RW + WR	633	33R	H48A	46R
Fu + uF	630	45	45	34
LF + FL	625	+56	44R	46S
CL + LC	623	67	44R	46R
RL + LR	621	36	44A	66R
iB + Bi	619	47	58	58
NL + LN	606	68R	46A	66S
GS + SG	603	55R	46R	46A
DW + WD	584	35A	68A	44R
NF + FN	583	58	46R	46S
Ki + iK	579	46S	57S	57R
Yi + iY	571	44A	35S	35R
NN	544	88K	66K	66K
RR	542	33K	44K	66K
ui + iu	532	44A	55S	35R
"T + T"	531	13R	16	67
KS + SK	530	+56	67	67
NH + HN	518	68S	66R	+56
NM + MN	511	88S	68R	68S
R. + .R	502	38	34	36
R, + ,R	500	38	34	36
.i + i.	499	H48A	35A	35S
YH + HY	498	46S	36	35S
TB + BT	495	H37S	68A	68A
–a + a–	495	25	25	35R
,i + i,	494	H48S	35R	35A
Y. + .Y	494	H48R	33A	33R
DM + MD	493	58	68S	H48R
Y, + ,Y	486	H48A	33R	33R
DY + YD	483	45	36	34
F. + .F	476	58	34	34
F, + ,F	471	58	34	34
RK + KR	468	36	47	67
PP	468	44K	33K	88K
'T + T'	459	23	67	67
DH + HD	451	+56	66S	45
e" + "e	449	13R	H15A	57S
.W + W.	444	38	38	34
D– + –D	441	25	H26R	34
,W + W,	440	38	38	34
151–200	+27,550			
1–200	471,009 = 92.3%			

APPENDIX 7. STATISTICAL USAGE OF 544 ADJACENCIES IN AVERAGE ENGLISH—Continued

Adja-cencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
DF + FD	439	55A	46S	44R
MM	434	88K	88K	88K
.H + H.	434	68R	36	35R
,H + H,	431	68A	36	35R
–o + o–	426	24A	25	35S
YW + WY	424	34	38	34
Qu	421	34	57R	23
DC + CD	402	57S	46A	44A
DB	398	57A	68S	H48R
N– + –N	397	H28R	H26A	36
YC + CY	395	47	34	34
GL + LG	394	+56	44R	46A
oK + Ko	378	46A	57R	57S
YP + PY	372	44R	33S	38
NB + BN	371	78	68R	68S
DG + GD	371	55A	46S	44A
PH + HP	357	46R	36	58
S" + "S	357	H15A	16	67
LW + WL	355	36	H48R	46S
DD	350	55K	66K	44K
," + ",	350	18	13R	H37A
.M + M.	336	88R	38	38
,M + M,	333	88A	38	38
L. + .L	325	68S	34	36
MB + BM	323	78	88S	88S
L, + ,L	322	68A	34	36
–i + i–	307	24R	25	35R
YF + FY	306	45	34	34
R– + –R	306	23	24A	36
DP + PD	305	45	36	H48A
Y– + –Y	303	24R	23	33S
.C + C.	300	78	34	34
,C + C,	299	78	34	34
NP + PN	296	H48R	36	68A
F– + –F	293	25	24R	34
.B + B.	292	78	38	38
GY + YG	290	45	34	34
,B + B,	290	78	38	38
FW + WF	289	35R	H48A	44S
G. + .G	286	58	34	34
G, + ,G	284	58	34	34
FH + HF	283	+56	46S	45
N' + 'N	283	H28S	67	67
"a + a"	281	H15S	H15R	57A
Ju	277	46S	57A	23
–W + W–	276	23	H28R	34
RV	273	H37S	H48S	68A
CC	270	77K	44K	44K
I#T + TI#	268	36	16	66A
Ze + eZ	267	H37A	58	25
201–250	+16,819			
1–250	487,828 = 95.7%			

Adja-cencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
Hu + uH	266	46S	+56	35A
–H + H–	264	H26R	H26R	35S
.P + P.	247	H48A	33A	38
,P + P,	246	H48R	33R	38
O#T + TO#	246	23	H26A	H26A
D" + "D	245	H15R	16	47
LM + ML	240	68R	H48R	68S
"o + o"	240	14	H15R	57A
iZ + Zi	239	47	58	25
aa	235	55K	55K	55K
LV	226	67	H48A	68R
eI# + I#e	225	36	H15A	+56
'S + S'	219	25	67	67
FM + MF	218	58	H48S	H48S
N" + "N	218	18	16	67
Xi + iX	214	47	57S	58
XP	214	47	H37S	88R
NV	208	78	68S	68R
LH + HL	207	66R	46R	+56
–M + M–	206	H28R	H28R	38
eJ + Je	204	36	57S	25
eO# + O#e	204	23	25	25
L– + –L	198	H26A	24S	36
HM + MH	196	68S	68S	58
FC + CF	195	57A	44A	44R
Jo + oJ	194	46R	57A	25
KT + TK	189	36	67	67
e' + 'e	189	23	57R	57A
GW + WG	187	35R	H48A	44A
FB + BF	186	57S	H48S	H48S
–B + B–	182	27	H28R	38
–C + C–	181	27	24R	34
SI# + I#S	178	+56	16	66R
"I + I"	174	14	H15S	57R
G– + –G	174	25	24R	34
Za + aZ	172	57S	58	25
GF + FG	170	55S	44S	44A
R" + "R	169	13R	14	67
GM + MG	168	58	H48S	H48A
eQ	166	33R	57A	25
Y" + "Y	166	14	13S	H37A
F" + "F	164	H15R	14	47
"W + W"	164	13A	18	47
SO# + O#S	161	25	H26R	H26S
FP + PF	154	45	34	H48A
–P + P–	153	24S	23	38
"H + H"	149	16	16	57A
i' + 'i	138	24A	57R	57A
I#a + aI#	137	+56	H15R	+56
HB + BH	136	67	68S	58
251–300	+9,821			
1–300	497,649 = 97.6%			

APPENDIX 7. STATISTICAL USAGE OF 544 ADJACENCIES IN AVERAGE ENGLISH—Continued

Adjacencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
2#T + T2#	136	13R	H26A	16
;T + T;	136	36	67	67
LK + KL	134	66A	47	67
O#a + aO#	129	25	25	25
GB	124	57S	H48S	H48A
XT	124	H37R	67	68R
DI# + I#D	123	+56	16	46R
GC	122	57A	44A	44R
Ja + aJ	122	+56	57R	25
o' + 'o	120	24R	57A	57R
I#o + oI#	119	46S	H15R	+56
DV	118	57A	68R	H48S
.u + u.	118	H48R	35A	33R
,u + u,	118	H48A	35R	33A
MW + WM	117	38	88A	H48S
"M + M"	117	18	18	78
e2# + 2#e	113	13R	25	H15R
e; + ;e	113	36	57R	57R
NI# + I#N	112	68R	16	66S
O#o + oO#	111	24S	25	25
DO# + O#D	111	25	H26S	24S
L" + "L	110	16	14	67
MC + CM	108	78	H48A	H48R
KW + WK	108	36	78	47
GG	108	55K	44K	44K
Yu + uY	107	44S	35S	33A
HH	106	66K	66K	55K
"C + C"	106	H17R	14	47
?T + T?	104	38	36	67
GP + PG	102	45	34	H48S
NO# + O#N	100	H28R	H26R	H26R
"B	98	H17R	18	78
Xa + aX	97	57A	57R	58
e? + ?e	97	38	35R	57A
G" + "G	96	H15R	14	47
XC	95	77A	47	H48S
'a + a'	93	25	57S	57S
D' + 'D	93	25	67	47
YY	92	44K	33K	33K
S2# + 2#S	92	H15A	H26R	16
S; + ;S	92	+56	67	67
K. + .K	90	68S	H37A	H37R
K, + ,K	90	68A	H37R	H37R
"P + P"	89	14	13S	78
RI# + I#R	86	36	14	66R
I#i + iI#	85	46A	H15S	+56
YI# + I#Y	85	46R	13S	36
FI# + I#F	83	+56	14	46S
:T + T:	81	36	36	67
O#i + iO#	80	24A	25	25
301–350	+5,310			
1–350	502,959 = 98.6%			

Adjacencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
VY + YV	79	47	38	38
'L + L'	77	H26R	47	67
RO# + O#R	77	23	24R	H26A
YO# + O#Y	77	24R	23	23
I#W + WI#	76	36	18	46S
FO# + O#F	75	25	24S	24R
I#H + HI#	75	66R	16	+56
KF + FK	74	+56	47	47
NJ	74	68S	67	H26R
e: + :e	74	36	35R	57R
KY + YK	73	46A	H37S	H37S
–u + u–	73	24R	25	33A
R' + 'R	73	23	47	67
WC + CW	72	H37A	H48S	44R
S? + ?S	72	58	36	67
ii	71	44K	55K	55K
O#W + WO#	71	23	H28A	24R
'M + M'	70	H28S	78	78
BJ	69	67	78	H28R
PW + WP	68	34	38	H48A
O#H + HO#	68	H26R	H26S	25
DK + KD	67	+56	67	47
2#a + a2#	67	H15S	25	H15A
;a + a;	67	+56	57S	57A
KB	63	67	78	78
D2# + 2#D	63	H15R	H26S	14
D; + ;D	63	+56	67	47
SV	62	57R	68A	68S
K– + –K	60	H26R	27	H37S
SQ	59	35A	67	H26A
WW	59	33K	88K	44K
DJ	58	+56	67	24A
2#o + o2#	58	14	25	H15R
;o + o;	58	46A	57A	57R
I#M + MI#	58	68R	18	68S
N2# + 2#N	57	18	H26R	16
N; + ;N	57	68R	67	67
Y' + 'Y	57	24S	H37R	H37R
uW + Wu	56	34	58	34
LI# + I#L	56	66K	14	66K
'W + W'	56	23	78	47
WB + BW	55	H37R	88A	H48S
TV	55	H37S	68A	68A
?a + a?	55	58	35S	57R
F' + 'F	55	25	47	47
KH + HK	54	66A	67	57S
NQ	54	38	67	H26R
S: + :S	54	+56	36	67
'C	53	27	47	47
O#M + MO#	53	H28R	H28S	H28R
351–400	+3,227			
1–400	506,186 = 99.3%			

APPENDIX 7. STATISTICAL USAGE OF 544 ADJACENCIES IN AVERAGE ENGLISH—Continued

Adjacencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
oX	51	47	57R	58
KM + MK	50	68A	78	78
BB	50	77K	88K	88K
?o + o?	50	H48A	35A	57S
D? + ?D	50	58	36	47
'H + H'	50	H26S	67	57R
LO# + O#L	50	H26S	24R	H26R
KG + GK	49	+56	47	47
I#B	49	67	18	68S
GI# + I#G	49	+56	14	46A
I#C	48	67	14	46R
I#P + PI#	46	46A	13S	68A
2#i + i2#	46	14	25	H15S
Y2# + 2#Y	46	14	23	13R
;i + i;	46	46R	57R	57S
Y; + ;Y	46	46R	H37R	H37R
N? + ?N	46	88R	36	67
SJ	45	+56	67	H26A
:a + a:	45	+56	35S	57A
" u +u"	44	14	H15S	H37S
O#B	44	27	H28S	H28R
O#C	44	27	24A	24A
GO# + O#G	44	25	24S	24A
R2# + 2#R	44	13R	24R	16
R; + ;R	44	36	47	67
'B	43	27	78	78
F2# + 2#F	43	H15R	24S	14
F; + ;F	43	+56	47	47
O#P + PO#	43	24A	23	H28A
TJ	41	36	67	H26R
XH	40	67	67	58
K" + "K	40	16	H17S	77A
.O# + O#.	40	H28S	23	23
O#O#	40	22K	22K	22K
Y? + ?Y	39	H48R	33R	H37S
.V	38	78	38	38
,V	38	78	38	38
D: + :D	38	+56	36	47
PB	37	47	38	88A
2#H + H2#	37	16	H26S	H15R
;H + H;	37	66R	67	57R
PC + CP	36	47	34	H48R
R? + ?R	36	38	34	67
:o + o:	36	46A	35A	57R
N: + :N	36	68R	36	67
2#W	34	13A	H28A	14
;W	34	36	78	47
G' + 'G	33	25	47	47
2#M + M2#	33	18	H28S	18
;M + M;	33	68R	78	78
401–450	+2,124			
1–450	508,310 = 99.7%			

Adjacencies	Usages per 510,000	Motion Codes QW*	DD**	MM***
KP	32	46R	H37S	78
F? + ?F	32	58	34	47
u' + 'u	31	24S	57R	H37A
TZ + ZT	30	H37R	68R	H26R
?i	30	H48R	35R	57R
?H +H?	30	68R	36	57S
.J	30	68R	H37S	23
,J	30	68A	H37A	23
,O# + O#,	30	H28A	23	23
L2# + 2#L	29	16	24R	16
L; + ;L	29	66A	47	67
R: + :R	29	36	34	67
YJ	28	46S	H37A	23
?M + M?	27	88R	38	78
RJ	26	36	47	H26S
G2# + 2#G	26	H15R	24S	14
G; + ;G	26	+56	47	47
F: + :F	25	+56	34	47
:H + H:	25	66R	36	57R
'P	25	24R	H37R	78
'V	25	27	78	78
?W	25	38	38	47
CB + BC	24	77A	H48A	H48R
2#B	24	H17R	H28S	18
2#C	24	H17R	24A	14
;B	24	67	78	78
;C	24	67	47	47
L? + ?L	24	68A	34	67
:M + M:	24	68R	38	78
–V	24	27	H28A	38
FV	23	57S	H48R	H48R
I#u + uI#	22	46R	H15S	36
:i	22	46R	35R	57S
G? + ?G	22	58	34	47
Y:	21	46R	33R	H37R
CQ	20	H37R	47	24S
NX	20	78	67	68R
uX	20	47	57S	38
–J	20	H26R	27	23
KO# + O#K	20	H26A	27	27
uO# + O#u	20	24R	25	23
L: + :L	20	66A	34	67
;W	20	36	38	47
.'	20	H28R	H37R	H37A
?B	19	78	38	78
FJ	18	+56	47	24R
2#P	18	14	23	18
;P	18	46S	H37R	78
?C	18	78	34	47
GV	16	57S	H48R	H48R
451–500	+1,209			
1–500	509,519 = 99.9%			

APPENDIX 7. STATISTICAL USAGE OF 544 ADJACENCIES IN AVERAGE ENGLISH—Continued

Adjacencies	Usages per 51,0000	QW* QW*	Motion Codes DD**	MM***
TQ	16	33R	67	H26R
DQ	15	35R	67	24A
:B	15	67	38	78
HV	14	67	68R	58
LJ	14	66R	47	H26R
:C	14	67	34	47
?P	14	H48S	33R	78
"V	13	H17R	18	78
GJ	12	+56	47	24R
O#V	12	27	H28R	H28S
YQ	11	34	H37R	23
:P	11	46S	33R	78
FQ	10	35R	47	24R
HJ	10	66S	67	25
Ku	10	46A	57S	H37A
LQ	10	36	47	H26R
MJ	10	68S	78	H28R
MV	10	78	88R	88R
NZ	10	78	68A	H26R
oQ	10	34	57S	25
RQ	10	33R	47	H26S
SZ	10	57A	68S	H26A
uu	10	44K	55K	33K
WV	10	H37R	88A	H48R
XS	10	57S	67	68A
XW	10	H37S	78	H48R
Zo	10	47	58	25
G:	10	+56	34	47
K'	10	H26A	77R	77R
KI#	10	66A	H17S	67
X.	10	78	H37A	38
X,	10	78	H37R	38
.Q	10	38	H37A	23
,Q	10	38	H37S	23
–Q	10	23	27	23
"Q	10	13S	H17R	27
"J	10	16	H17A	27
O#J	10	H26R	27	22A
I#V	10	67	18	68R
2#u	10	14	25	13R
;u	10	46R	57R	H37R
..	10	88K	33K	33K
--	10	22K	22K	33K
?"	10	18	13R	77A
501–544	+481			
1–544	510,000 = 100.0%			

Summary by Motion Codes

Motions by motion codes:	QWERT YUIOP per 510,000	1000	DVORAK–DEALEY per 510,000	1000	MINIMOTION per 510,000	1000
11	0	0	0	0	0	0
13	1,650	3	746	2	56	0
H15	1,434	3	1,776	3	321	1
H17	265	0	70	0	0	0
33	37,975	75	2,500	5	1,821	4
35	62,883	123	22,341	44	23,713	46
H37	18,004	35	804	2	1,107	2
55	19,390	38	27,380	53	44,443	87
57	10,603	21	6,236	12	5,626	11
77	439	1	10	0	60	0
Left-handed motions	152,643	299	61,863	121	77,147	151
22	50	0	50	0	50	0
24	1,964	4	1,608	3	478	1
H26	827	2	3,754	7	1,033	2
H28	1,199	2	959	2	231	0
44	17,405	34	10,736	21	4,268	8
46	21,405	42	32,145	63	34,475	68
H48	36,107	71	5,976	12	2,828	6
66	3,648	7	48,211	95	34,736	68
68	4,466	9	10,772	21	12,941	25
88	3,534	7	1,058	2	2,311	5
Right-handed motions	90,605	178	115,269	226	93,351	183
12	0	0	0	0	0	0
14	891	2	967	2	190	0
16	375	1	2,256	4	358	1
18	785	2	585	1	75	0
23	3,724	7	710	1	1,014	2
25	3,050	6	2,949	6	1,986	4
27	608	1	120	0	40	0
34	55,488	109	11,449	23	11,151	22
36	43,518	85	17,014	33	30,239	59
38	31,103	61	5,360	11	7,796	15
45	45,109	88	94,629	186	67,110	132
47	16,320	32	2,100	4	2,510	5
56	20,769	41	146,942	288	170,929	335
58	35,636	70	43,651	86	39,961	78
67	5,324	10	3,541	7	5,333	11
78	4,052	8	595	1	810	2
Two-handed motions	266,752	523	332,868	653	339,502	666
One-handed motions	243,248	477	177,132	347	170,498	334
Total Motions	510,000	1000	510,000	1000	510,000	1000
Left-handed motions	152,643	299	61,863	121	77,147	151
Two-handed motions/2	133,376	262	166,434	326	169,751	333
Left-handed strokes	286,019	561	228,297	447	246,898	484
Right-handed motions	90,605	178	115,269	226	93,351	183
Two-handed motions/2	133,376	261	166,434	327	169,751	333
Right-handed strokes	223,981	439	281,703	553	263,102	516
Total Strokes	510,000	1000	510,000	1000	510,000	1000

Continued on p. 436.

APPENDIX 8. STATISTICAL USAGE OF SINGLE STROKES AND ADJACENCIES IN AVERAGE ENGLISH, PER 510,000 STROKES

(With the two orders of each adjacency (as TH and HT) added together and entered twice for 1,020,000 total)

	a	e	i	o	u	vow	B	C	D	F	G	H	J	K	L	M	N	P	Q	R
a	470	4881	2712	908	978	9949	1526	5792	5557	1405	1594	4770	122	757	5427	3208	10000	1957		7485
e	4881	4450	5118	1889	826	15144	5549	4509	7098	2078	2284	15135	204	1190	5782	5463	9109	2754	166	14605
i	2712	5118	142	2992	532	9496	619	3705	3085	2226	1833	3642		579	4501	2559	11052	942		4576
o	908	1889	2992	2552	4737	15078	1250	3528	2205	6747	1187	2493	194	378	2567	3514	8918	2222	10	7805
u	978	826	532	4737	20	7093	1514	1095	713	630	960	266	277	10	1762	925	2315	1045	421	2751
vow	9949	15144	9496	15078	7093	54760	8058	16650	18456	13084	7858	24306	797	2914	20059	15669	41394	8880	597	37018
B	1526	5549	619	1250	1514	8058	100	24	398	186	124	156	69	63	1092	525	571	57		766
C	5792	4509	3705	3528	1095	16650	24	540	402	195	122	2174		705	625	108	1688	36	20	979
D	5557	7098	3085	2205	715	18456	398	402	700	439	371	451	58	67	1721	495	6214	305	15	1405
F	1405	2078	2226	6747	630	13084	186	195	439	1300	170	283	18	74	625	218	585	154	10	1280
G	1594	2284	1833	1187	960	7858	124	122	371	170	216	1305	12	49	394	168	4441	102		1305
H	4770	15135	3642	2493	266	24306	156	2174	451	283	1305	212	10	54	207	196	518	357		705
J	122	204		194	277	797	69		58	18	12	10			14	10	74			26
K	757	1190	579	378	10	2914	63	705	67	74	49	54			154	50	646	32		468
L	5427	5782	4501	2567	1762	20059	1092	623	1721	625	394	207	14	154	5742	240	606	1244	10	621
M	3208	5463	2559	3514	925	15669	323	108	495	218	168	196	10	50	240	868	511	775		976
N	10000	9109	11052	8918	2315	41394	571	1688	6214	585	4441	518	74	646	606	511	1088	296	54	979
P	1957	2754	942	2222	1045	8880	57	36	305	154	102	357		52	1244	775	296	956		1681
Q		166		10	421	597		20	15	10					10		54			10
R	7485	14605	4576	7805	2751	37018	766	979	1405	1260	1305	705	26	468	621	976	979	1681	10	1084
S	5846	8531	6735	3351	3056	27499	636	1064	1352	675	605	2050	45	550	977	907	2551	1231	59	2196
T	9144	9075	9428	7144	2518	37307	495	1737	1561	1300	697	15952	41	189	1587	698	4919	656	16	4000
V	1850	4572	1805	827		8852			118	25	16	14			226	10	208			275
W	2468	3323	1851	2706	56	10584	55	72	584	289	187	1958		108	355	117	884	68		633
X	97	681	214	51	20	1063		96				40					20	214		
Y	1986	1561	571	1968	107	6193	883	595	483	508	290	498	28	75	1879	753	782	572	11	1567
Z	172	267	259	10		688											10			
CONS	66719	99712	59941	59055	20241	305668	5758	10977	17155	8108	10574	27122	405	3240	18297	7421	27443	8496	205	20734
,	796	1518	494	668	118	3414	290	299	714	471	284	451	30	90	522	353	644	246	10	500
.	805	1528	499	695	118	3445	292	300	720	476	286	434	30	90	525	356	649	247	10	502
-	495	810	307	425	75	2111	182	181	441	295	174	264	20	60	198	208	397	153	10	308
'	281	449	174	240	44	1188	98	106	245	164	96	149	10	40	110	117	218	89	10	169
"	95	189	158	120	31	571	43	53	95	55	33	50		10	77	70	283	25		78
Q#	129	204	80	111	20	544	44	44	111	75	44	68	10	20	50	53	100	43		77
1#	157	225	85	119	22	588	49	48	125	85	49	75		10	56	58	112	46		86
2#	67	113	46	58	10	294	24	24	65	43	26	37			29	33	57	18		44
;	67	113	46	58	10	294	24	24	65	43	26	37			29	33	57	18		44
?	55	97	30	50		232	19	18	50	32	22	30			24	27	45	14		36
:	45	74	22	36		177	15	14	38	25	10	25			20	24	36	11		29
P+N	2970	4920	1921	2601	446	12858	1080	1111	2661	1760	1050	1600	100	320	1240	1290	2599	910	40	1866
ΣΣ	79658	119776	71558	74752	27780	373284	14896	28718	36232	22952	19482	53028	1502	6474	39576	24380	71436	18286	842	59618

	S	T	V	W	X	Y	Z	CON
a	5646	9144	1650	2468	97	1986	172	66719
e	8531	9075	4572	3325	681	1561	267	99712
i	6735	9428	1805	1851	214	571	239	59941
o	3331	7144	827	2706	51	1968	10	59053
u	3056	2518		56	20	107		20841
vow	27499	37307	8852	10584	1063	6193	688	305666
B	656	496		55		883		5758
C	1064	1737		72	95	595		10977
D	1552	1561	118	584		483		17135
F	675	1300	23	289		306		8108
G	603	697	16	187		290		10574
H	2050	15952	14	1958	40	498		27122
J	45	41				23		405
K	550	189		108		73		5240
L	977	1587	226	355		1879		18297
M	907	698	10	117		753		7421
N	2551	4919	208	884	20	782	10	27443
P	1231	656		68	214	372		8496
Q	59	16				11		205
R	2196	4000	273	633		1367		20734
S	4514	7057	62	992	10	1011	10	28532
T	7057	4658	55	1006	124	2107	30	48885
V	62	55		10		79		1094
W	992	1006	10	118	10	424		7870
X	10	124		10				513
Y	1011	2107	79	424		184		11925
Z	10	30						50
CON	28532	48885	1094	7870	513	11925	50	264784
,	1050	1538	38	440	10	486		8206
.	1040	1552	38	444	10	494		8275
-	654	947	24	276		303		5069
"	357	531	15	164		166		2852
'	219	459	25	56		57		1681
0#	161	246	12	71		77		1306
1#	178	268	10	76		85		1412
2#	92	156		54		46		706
;	92	156		54		46		706
?	72	104		25		39		556
:	54	81		20		21		425
P+N	3929	5998	160	1640	20	1820		31194
2Σ	59960	92190	10106	19894	1596	19958	738	601644

	,	.	-	"	'	0#	1#	2#	;	?	:	P+N	2Σ
a	796	805	496	281	93	129	137	67	67	55	45	2970	79838
e	1518	1528	810	449	189	204	225	113	113	97	74	4920	119776
i	494	499	307	174	138	80	85	46	46	30	22	1921	71558
o	688	695	426	240	120	111	119	58	58	50	36	2601	74732
u	118	118	73	44	31	20	22	10	10			446	27780
vow	3414	3445	2111	1188	571	544	588	294	294	232	177	12858	373284
B	290	292	182	98	43	44	49	24	24	19	15	1080	14896
C	299	300	181	106	53	44	48	24	24	18	14	1111	28718
D	714	720	441	245	93	111	123	63	63	50	38	2561	36232
F	471	476	295	164	55	75	83	43	43	32	25	1760	22952
G	284	286	174	96	53	44	49	26	26	22	10	1050	19482
H	431	434	264	149	50	68	75	37	37	30	25	1600	53028
J	30	30	20	10		10						100	1302
K	90	90	60	40	10	20	10					320	6474
L	322	325	198	110	77	50	56	29	29	24	20	1240	39576
M	333	336	206	117	70	53	58	33	33	27	24	1290	24380
N	644	649	397	218	283	100	112	57	57	46	36	2599	71436
P	246	247	153	89	25	43	46	18	18	14	11	910	18286
Q	10	10	10	10								40	842
R	500	502	306	169	73	77	86	44	44	36	29	1866	59618
S	1050	1040	634	357	219	161	178	92	92	72	54	3929	59960
T	1538	1552	947	531	459	246	268	136	136	104	81	5998	92190
V	38	38	24	15	25	12	10					160	10106
W	440	444	276	164	56	71	76	34	34	25	20	1640	19894
X	10	10										20	1596
Y	486	494	303	186	57	77	85	46	46	39	21	1820	19958
Z													738
CON	8206	8275	5069	2852	1681	1306	1412	706	706	556	423	31194	601644
,				350		30						380	12000
.		80			20	40						80	11800
-			20									20	7200
"	350									10		360	4400
'		20										20	2272
0#	30	40				80						150	2000
1#													2000
2#													1000
;													1000
?				10								10	800
:													600
P+N	380	80	20	360	20	150				10		1020	45072
2Σ	12000	11800	7200	4400	2272	2000	2000	1000	1000	800	600	45072	1020000

Fingering of one handed motions:

		QWERT YUIOP		DVORAK–DEALEY		MINIMOTION	
		per		per		per	
		510,000	1000	510,000	1000	510,000	1000
Non-hurdles, left	K	9,065	18	4,377	9	4,025	8
	S	17,766	34	7,268	14	9,195	18
	A	56,296	111	17,975	36	36,330	71
	R	49,813	98	29,593	57	26,169	51
		132,940	261	59,213	116	75,719	148
Non-hurdles, right	K	5,988	12	10,620	21	11,028	22
	S	6,556	13	9,869	19	10,134	20
	A	19,894	39	49,706	97	34,309	67
	R	20,034	39	34,385	68	33,788	66
		52,472	103	104,580	205	89,259	175
Non-hurdles, total	K	15,053	30	14,997	30	15,053	30
	S	24,322	47	17,137	33	19,329	38
	A	76,190	150	67,681	133	70,639	138
	R	69,847	137	63,978	125	59,957	117
		185,412	364	163,793	321	164,978	323
Hurdles, left	S	6,456	13	734	2	262	1
	A	12,106	23	852	1	644	1
	R	1,141	2	1,064	2	522	1
		19,703	38	2,650	5	1,428	3
Hurdles, right	S	6,471	13	2,108	4	1,100	2
	A	15,957	31	2,375	5	1,315	3
	R	15,705	31	6,206	12	1,677	3
		38,133	75	10,689	21	4,092	8
Hurdles, total	S	12,927	26	2,842	6	1,362	3
	A	28,063	54	3,227	6	1,959	4
	R	16,846	33	7,270	14	2,199	4
		57,836	113	13,339	26	5,520	11
Total one-handed	K	15,053	30	14,997	30	15,053	30
	S	37,249	73	19,979	39	20,691	41
	A	104,253	204	70,908	139	72,598	142
	R	86,693	170	71,248	139	62,156	121
		243,248	477	177,132	347	170,498	334
Total, two-handed		266,752	523	332,868	653	339,502	666
Total Motions		510,000	1000	510,000	1000	510,000	1000

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

SUBMINIATURIZATION OF INTERMEDIATE FREQUENCY AMPLIFIERS

In military applications of miniature electronic systems, ease of mass production is as important as reduction in size. This requirement has motivated the search for new techniques and materials to use in the manufacture of electronic equipment. The National Bureau of Standards, under the sponsorship of the Bureau of Aeronautics, Department of the Navy, is engaged in adapting these techniques to the production of more complicated *subminiature* electronic devices, such as broad-band, high-gain, intermediate-frequency amplifiers for aircraft and missiles.

The intermediate-frequency amplifier chosen for miniaturization embodies a type of critical circuit layout that presents the most typical problems. The miniaturized amplifier was designed to have (*a*) eight stagger-tuned intermediate-frequency stages, a detector, a video amplifier, and a cathode-follower output circuit; (*b*) more than 95 decibels gain from the intermediate-frequency input to output of the detector; (*c*) manual and automatic gain control; (*d*) a 60-megacycle center frequency and a band-width of 10 megacycles; and (*e*) an assembly readily adaptable to mass-production methods.

Two methods of fabrication were employed in the construction of miniaturized intermediate-frequency amplifiers. One unit was developed using a maximum of miniature component parts based on standard design, whereas a second assembly used a maximum of printed circuits.

In the development of high-temperature printed resistors, simple high-capacity printing equipment for establishing the circuitry on the special cylindrical ceramic parts has been designed and constructed. Conductive decalcomanias have been developed as an alternate method of applying the required multiple circuit elements.

Other production jigs and techniques to facilitate the production of the intermediate-frequency amplifier have been developed for greater mechanization of printed circuit processing. Experience gained on this development program points the way toward even smaller and lighter printed and miniature component assemblies.

HELIUM DISAPPEARANCE IN ARC DISCHARGE TUBES

Electron tubes filled with a noble gas such as argon, neon, or helium are now widely employed in many kinds of electronic equipment, and

* Communicated by the Director.

the problem of gas disappearance in these tubes is of considerable importance. This tendency of filler gases to disappear from the tube volume is known as "clean-up" and is generally thought to result from the bombardment of negatively charged electrodes by high-velocity positive gas ions that penetrate the metal surfaces and become permanently trapped.

The National Bureau of Standards has been carrying on a study of clean-up phenomena in a specially designed discharge tube with a replaceable tantalum probe wire to collect the positive ions. During operation, the rate of gas clean-up is measured for various negative direct-current potentials on the probe in the presence of an arc discharge. In addition to the probe wire, this helium-filled discharge tube employs an oxide-coated cathode and a nickel anode.

With a known tube volume, the total number of ions trapped during a test run may be computed from the observed drop in pressure, whereas the number of ions striking the probe can be found directly from the observed probe current. These data have been used to construct a graph that illustrates the dependence of clean-up on probe voltage.

A PRIMARY HIGH-FREQUENCY VOLTAGE STANDARD

The National Bureau of Standards is developing primary standards of voltage for radio frequencies up to several hundred megacycles. Precision voltage standards are urgently needed by communications services and research groups in the adjustment of many laboratory and field instruments operating at high frequencies.

The Bureau has concentrated on methods of measuring single-frequency voltages directly in terms of a standard direct-current cell. Specific techniques have been chosen for best time-efficiency and accuracy over the widest range of voltage and frequency, without using frequency corrections. Reliability has been achieved by cross-checking the results of several independent methods based on different principles. Reproducibility of results and agreement between individual primary-standard methods is required within $\pm$ 1 per cent, since measurements to that accuracy are considered to be of good precision in the high-frequency region.

One of the techniques developed by the Bureau that satisfactorily meets the basic requirements for a primary standard is the voltage-measuring bolometer bridge, utilizing the dependence of bolometer resistance on power dissipation. In this method, a direct-current bridge with a bolometer in one of its legs is first balanced on direct current. Radio-frequency power is then substituted for some of the direct-current power and the bridge is rebalanced. The amount of radio-frequency power equals the difference in direct-current power required for balance in each case.

EFFECTS OF ACID TREATMENT ON ABRASION AND ACID RESISTANCE OF PORCELAIN ENAMELS

Recent work at the National Bureau of Standards has revealed the effects of acid pretreatment of porcelain enamels upon their acid and abrasion resistance. Studies were made to compare the relative effects of hydrochloric, acetic, butyric, and citric acids on a number of enamels. These studies indicate that acetic acid is much less corrosive than hydrochloric and citric acids; moreover, treatment with acetic or butyric acid, which produces only minor visible attack, strongly inhibites further attack when the specimens are subsequently treated with citric acid. By comparison, citric acid severely attacked the untreated areas of the same enameled specimens. In other tests, the resistance of certain enamels to abrasion was appreciably reduced after they had been treated with any of the acids.

Both effects, the increase in acid resistance and the decrease in abrasion resistance, may be explained by the hypothesis that a silica-rich film is formed on the enameled surface by the acetic and butyric acids. This layer is then resistant to further attack even by citric or stronger acids. However, it is less resistant to abrasion than the original surface.

The increased use of titanium-type enamels and the sensitivity of these enamels to attack by abrasion after treatment with acid, as compared with antimony-type enamels, indicates that an abrasion treatment should be incorporated in the standard test for acid resistance.

IMPROVEMENT OF LABORATORY GAS BURNERS

Marked improvement in the performance of laboratory-type gas burners with natural gas has been accomplished through design changes worked out at the National Bureau of Standards. Basic principles of gas-burner design and analysis of the operating characteristics of commercial and experimental burners were applied.

The difference in flame characteristics between natural and manufactured gas necessitates the alteration of all gas-burning appliances when a change in supply is made. The exacting requirements of Bunsen and similar types of laboratory burners, however, have made it much more difficult to convert these devices to the use of natural gas than has been true of domestic appliances. Even those burners advertised as designed for natural gas have not proven satisfactory. Eight Meker type and eight straight-tube Bunsen burners were examined in the Bureau's gas chemistry laboratory and the changes required for satisfactory operation determined.

These changes included an increase in the primary air opening to $2\frac{1}{4}$ times the port area and, in the Meker burner, enlargement of the

port area to 2½ times the throat area. The orifice should also be of sufficient size to give the maximum gas rate when fully opened and the needle valve used only to reduce the flow of gas. Only after these adjustments had been made did the burners reach their maximum heats of 10,000 Btu. per hour for Meker types and 5,000 Btu. for straight-tube types. As a result of this research, several manufacturers are redesigning their burners and the improved appliances will be available in the near future.

STABILITY TEST FOR ADDITIVE-MOTOR OILS

A new evaluation test for lubricating oils with additives, which simulates the characteristic deposits found in engine tests of motor oils, has been developed in the National Bureau of Standards' lubrication laboratory. The method has several advantages over the present testing procedure, which requires disassembly of the test engine and an examination of its parts. It employs simple laboratory apparatus, is time saving, is less expensive, and eliminates the fuel variable that results from contamination of the oil by the engine fuel. Most important, it gives a quantitative as well as visual rating of an oil.

The new test method consists essentially of circulating the oil sample over a heated steel strip in a thin film quite similar to the oil film on an engine cylinder wall. The difference in weight of the strip before and after the test provides a numerical indication of the amount of deposit formed.

In general, the oils used in the Bureau's investigation are in commercial production and have a considerable background of service performance. They include oils with no additives, premium-type additive oils containing inhibitors and/or detergents, and full heavy-duty oils containing additives. Data obtained with the new test, therefore, give a sensitive indication of the effectiveness of inhibitors, detergents, and their combinations.

SAMPLING PLAN REDUCES INSPECTION COSTS

Whenever industrial and agricultural products are purchased in quantity, the buyer must employ some sort of inspection procedure to determine whether or not the material meets the specified standard of quality. The extent of this inspection will depend on the nature of the material and may range all the way from a rough appraisal based on an examination of a few items to the complete inspection of each item. The decision to accept or reject a given lot of material is often determined by the average quality of a random sample taken from the lot. Whenever such a routine acceptance test is conducted, any way of reducing the amount of inspection, and therefore the cost, is worth exploring.

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The Statistical Engineering laboratory of the National Bureau of Standards has developed a modified double sampling plan that makes possible a saving in the average amount of inspection from 20–40 per cent. In this new plan, the regular testing procedure is interrupted after a predetermined number of units have been examined. The material is accepted if the test results at the time of interruption fulfill the criteria of a simple rule that requires neither computation nor the use of tables. If the material does not pass this test, the inspection is completed in the usual manner. In either case, the inspection procedure itself remains unchanged.

The modified double sampling plan developed at the National Bureau of Standards is a substitute for the usual single sampling plan that does not alter the sampling itself or require additional computation. In this new plan the same number of units is drawn as in the single sample case, but the regular testing procedure is interrupted after a fixed number of items have been tested. If a predetermined number of these test results individually exceed the acceptance value of the original plan, the material is immediately accepted and testing stopped. If less than the required number meet the acceptance value, testing is completed in the usual way and the individual test results are averaged. Acceptance or rejection then depends on whether or not this average exceeds the acceptance value.

The chance that material of a given quality will be accepted under the modified double sampling plan is thus slightly larger than on the original single sample plan, since there will be some samples which have the required number of items exceeding the acceptance value at the point where inspection is interrupted, but which, if completely inspected, would have yielded an overall average below the acceptance value. This increase in the chance of acceptance is desirable when the general quality of the material under inspection is known to be good. It is undesirable when the quality is bad, and this slight increase in the chance of accepting bad material is the price to be paid for reducing the average amount of inspection without disturbing existing routines.

No sampling plan can guarantee the rejection of unserviceable material, but the chance of accepting such material can be made as small as desired by properly choosing the acceptance value and the number of units to be tested.

THE FRANKLIN INSTITUTE.

MEDAL DAY MEETING

WEDNESDAY, OCTOBER 19, 1949

The Annual Medal Day Exercises of The Franklin Institute were held on Wednesday, October 19, 1949 in the Benjamin Franklin Memorial Hall. There were approximately 300 persons who attended the dinner and the presentation of the awards. Twenty three of our former medalists were among the guests present.

Prior to the dinner, a reception in honor of the 1949 Medalists was held in the rooms adjoining the Memorial Hall.

The Medal Day Exercises opened with Mr. Guy Marriner, Director of Music at The Franklin Institute, playing the National Anthem. Mr. Richard T. Nalle, President, officiated at the ceremonies.

The Stated Monthly meeting of The Franklin Institute was held in conjunction with the Medal Day Exercises but the minutes of the previous meeting were not read since they had been printed in full in the JOURNAL. Mr. Nalle reported that Dr. Svedberg had been nominated by the Board of Managers for Honorary Membership in The Franklin Institute, he therefore presented his name to the membership for voting. A motion was made, approved and carried out in parlimentary procedure and Dr. Svedberg was elected to Honorary Membership in The Franklin Institute.

Two of our honored medalists, Dr. The Svedberg of Sweden, and Dr. William Hume-Rothery, of England were unable to be present and their awards were presented *in absentia*. Mr. Ingemar Hägglöf, Counselor of the Swedish Embassy in Washington, received the award for Dr. Svedberg and Dr. W. A. Macfarlane, Scientific Attaché of the British Embassy received the award for Dr. Hume-Rothery.

Mr. William Hulse Millspaugh had arrived in Philadelphia with the hope of being present at the presentation of his award but was stricken seriously ill and taken directly to the hospital. Dr. Henry B. Allen, Executive Vice President and Secretary of the Institute, acted as Mr. Millspaugh's proxy.

Dr. Allen presented a short paper on "The Franklin Institute in 1949" and Mr. J. Burton Nichols delivered Dr. Svedberg's address "Giant Molecules in Solution." These papers and the entire proceedings will be printed in full in a subsequent issue of the JOURNAL OF THE FRANKLIN INSTITUTE.

PROGRAM

Reception for Medalists	THE HOSTESS COMMITTEE
Assembly in Franklin Hall	Upon gong signal at seven-ten
National Anthem	GUY MARRINER
Dinner	MEDALISTS, OFFICIALS AND GUESTS
Toast to Benjamin Franklin	RICHARD T. NALLE, *President*
Greetings	THE PRESIDENT
October Stated Meeting of The Institute	THE PRESIDENT PRESIDING
Introduction of Former Medalists	THE PRESIDENT
The Institute in 1949	HENRY B. ALLEN, *Secretary*
Presentation of Awards	THE PRESIDENT
Presentation of Dr. Svedberg's paper on "Giant Molecules in Solution" (Read by Dr. J. Burton Nichols, in the absence of Dr. Svedberg.)	

MEDALISTS

To be Awarded Longstreth Medals (1890)

ARTHUR M. YOUNG
New York City, New York

WILLIAM H. MILLSPAUGH (*in absentia*)
President and Director, Centrifugal Steel, Inc.
Sandusky, Ohio

To be Awarded Potts Medals (1906)

JOHN WILLIAM MAUCHLY
President, Eckert-Mauchly Computer Corporation
Philadelphia, Pennsylvania

J. PRESPER ECKERT, JR.
Vice President, Eckert-Mauchly Computer Corporation
Philadelphia, Pennsylvania

CLINTON RICHARDS HANNA
Associate Director of Research
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

To be Awarded a Levy Medal (1923)

ALAN STEWART FITZGERALD
Consulting Engineer
San Francisco, California

To be Awarded a Henderson Medal (1924)

JOHN V. B. DUER
Pennsylvania Railroad (Retired)
Fairfield, Connecticut

To be Awarded Wetherill Medals (1925)

HARLAN D. FOWLER
Consulting Engineer
Whittier, California

THOMAS L. FAWICK
President, Fawick Airflex Company, Inc.
Cleveland, Ohio

EDGAR COLLINS BAIN
Vice President, Carnegie-Illinois Steel Corporation
Pittsburgh, Pennsylvania

To be Awarded a Clamer Medal (1943)

WILLIAM HUME-ROTHERY (*in absentia*)
Royal Society Warren Research Lecturer
Metallurgical Chemistry
University of Oxford, England

To be Awarded a Ballantine Medal (1946)

SERGEI A. SCHELKUNOFF
Research Mathematician
Bell Telephone Laboratories
Murray Hill, New Jersey

To be Awarded the Franklin Medal (1914) and a Certificate of Honorary Membership in The Franklin Institute

THE SVEDBERG (*in absentia*)
Director
The Gustav Werner Institute for Nuclear Chemistry
Upsala, Sweden

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, October 12, 1949.)

HALL OF THE COMMITTEE,
PHILADELPHIA, OCTOBER 12, 1949.

MR. W. LAURENCE LEPAGE in the Chair

The following reports were presented for final action:

No. 3196: Work of Merle A. Tuve on the Proximity Fuze Development.

This report recommended the award of a Howard N. Potts Medal to Merle A. Tuve, of Washington, D. C., "In recognition of the scientific insight exhibited in the conception of the VT Proximity Fuze and of the administrative ability and practical good judgment shown in the supervision of its development and engineering design."

No. 3200: 20,000,000-Volt Betatron.

This report recommended the award of a John Price Wetherill Medal to Donald William Kerst, of Urbana, Illinois, "In consideration of his contribution to the theory of the Betatron and the practical application of the theory to the construction of the first satisfactory workable machine, and his subsequent work in this field."

JOHN FRAZER,
Secretary to Committee.

MUSEUM NOTES

RADIOSONDES

The weather is always with us but beyond keeping an umbrella and rubbers within convenient range, few of us do much else about it. However, weather is a matter of primary importance to some people and their needs justify the development of methods for securing more comprehensive and accurate data. An interesting feature of modern meteorological investigation is the radiosonde, a combination of devices for obtaining information on conditions prevailing at altitudes up to more than 100,000 ft. The information thus obtained may have an immediate use or it may be required for comparative purposes in the assembly of data to provide a basis for forecasts.

The immediate uses for information of this nature will be recognized as of high importance for aviation, especially in relation to jet propelled aircraft. Not so obvious is the need for the artillerist whose projectiles may rise above surface conditions and who must know the conditions prevailing at the altitudes through which the projectile must travel. Knowledge of this nature is imperative to permit correction of gun sighting.

The Signal Corps of the United States Army is responsible for the collection and dissemination of meteorological data and the Evans Signal Laboratory at Fort Monmouth, N. J. has made some impressive improvements in the radiosonde, the assembly of measuring devices sent into the upper air. The Evans Laboratory has designed and built a special exhibit for the Museum which illustrates the progressive steps in the development of the instruments and the construction and use of the radiosonde now employed by the Signal Corps. The exhibit shows very clearly what rapid strides have been made in the improvement in the device during its twenty years of existence.

The dispatch of human agents into the upper air by means of balloon or other aircraft is an expensive undertaking not unaccompanied with danger. There is, too, a somewhat restricted ceiling. The purpose of the radiosonde is to render unnecessary any human flight into the air. The attainable ceiling is accordingly very much elevated.

The radiosonde now in use has been carried to altitudes exceeding 100,000 ft. The desirable ceiling is about 150,000 ft. and the additional distance presents a problem out of all proportion. When one realizes that the diminishing air pressure implies a proportional expansion of the gas within the balloon it will be seen that the greatest obstacle to increasing the altitudes to which a gas-filled balloon may ascend resides in the difficulty of finding an elastic fabric for the balloons.

Any radiosonde system dispatched into the air must convey its own means for making measurements and for transmitting the results obtained to a receiving station, since the chance of recovering the instruments uninjured is small. The device developed by the Evans Laboratory is a marvel of compactness and comprises the radiosonde (which is the assembly of measuring instruments), a power source, balloon, parachute and, under conditions of high or gusty winds, a launching wheel in addition to the component parts of the permanent station equipment. The latter comprises a meteorological direction-finder which tracks the radiosonde, and a recording apparatus for making a permanent record of the data emitted by the measuring instruments.

The instruments carried into the upper air by the radiosonde assembly are very tiny but they are capable of accurately measuring five meteorological quantities—atmospheric pressure, temperature, relative humidity, wind velocity, and direction. All of these data are collected on a single ascent, and transmitted by a battery-powered radio transmitter to the ground station where they are automatically recorded.

At the present time radiosondes are released twice daily from seventy different places in this country. Each one faithfully records the local conditions but all gathered together furnish data upon which more general pictures of the weather may be built and forecasts made.

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THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

***Abstract of* Measurement of the Spin of a Projectile in Flight.**[1]—HOWARD D. WARSHAW.[2] Projectile spin is measured by recording the voltage generated in a pick-up coil as the rotating field of a transversely magnetized projectile passes the coil.

A permanent magnet within a brass sleeve (for magnetic insulation) is inserted in a projectile of mild steel. Rotation of the projectile as it passes the pick-up coil generates a sinusoidal e.m.f. which is displayed on the screen of a cathode-ray tube and photographed for subsequent analysis. Figure 1 shows the laboratory setup and a block diagram of the associated equipment used for measuring and recording projectile spin. The pick-up coil consists of insulated copper wire, wound on a rectangular coil form which is positioned so that its long sides are parallel to the line of flight. As the rotating projectile passes the coil, a voltage is generated in that side of the coil nearest the line of flight. Any voltage generated in the opposite side of the coil will reduce the signal output, which is the difference in voltage generated in the two sides. However, the signal reduction is negligible since the intensity of the magnetic field due to the projectile is negligible at the far side of the coil.

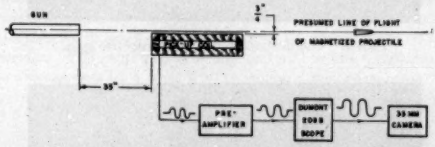

FIG. 1. Gun, pick-up coil, and recording equipment (pick-up coil viewed from above).

The signal output of the coil is passed through a pre-amplifier and then to the vertical deflection amplifier of a Dumont, Type 208B, cathode-ray oscilloscope. The over-all voltage amplification of the system is approximately 10,000. The oscilloscope, modified for single sweep, is triggered by a switch in the breech mechanism of the gun. Permanent records are obtained by photographing the trace that appears on the screen when the projectile passes the coil.

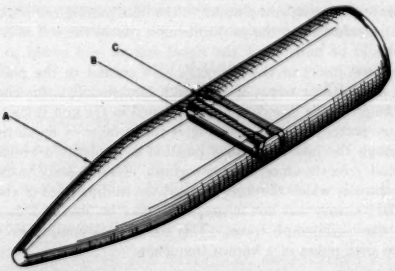

FIG. 2. Cut-away sketch of projectile. (A) Cold-rolled steel projectile. (B) Magnetic insulator (brass sleeve). (C) Magnetized insert (hardened drill rod).

[1] Paper based on work done for the Office, Chief of Ordnance, Department of the Army. Published in *The Review of Scientific Instruments*, Vol. 20, No. 7, July, 1949.

[2] Research Engineer, The Franklin Institute Laboratories for Research and Development, Philadelphia 3, Pa.

The caliber 0.50 projectiles used in these tests were made of cold-rolled steel. This material has high magnetic permeability but low retentivity. A satisfactory design was evolved in which a hardened steel insert was magnetically insulated from the projectile, as shown in Fig. 2.

Figures 3 and 4 are photographic records obtained with the equipment described. Calculations based on the linear velocity of the projectile and the rifling twist in the gun indicate that the projectile should execute two full revolutions while passing the pick-up coil. In Fig. 3, it may be seen that two complete sine waves of voltage were generated in the pick-up coil. However, due to the spurious signal that preceded the desired signal, the base line of the sine waves is not parallel to the zero-signal base line (at the extreme left end of the trace). The true base line is midway between, and parallel to the lines joining the peaks of the sine waves. Thus, the number of revolutions of the projectile as it passes the coil may be determined.

FIG. 3. Oscilloscope record of projectile spin.

FIG. 4. Oscilloscope record of projectile spin.

In Fig. 3, it should be noted that the signal started and ended at zero voltage. Apparently, the magnetized insert in the projectile was normal to the plane of the coil when passing the leading and trailing edges of the coil. Occasionally, this condition may be duplicated, provided the projectile is accurately positioned in the gun prior to firing. However, this is not a necessary prerequisite, since in Fig. 4 the number of revolutions was determined accurately, even though the insert was in a position to generate a voltage as it passed the leading edge of the coil. As shown on the photograph, it is necessary to extrapolate the signal to the point on the trace at which the insert passed the leading edge of the coil.

Although angular velocity was not measured, it may be obtained simply by the addition of time-markers to the oscillograph trace. This could be accomplished by modulating the intensity of the trace with pulses of a known frequency.

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JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the JOURNAL within the next few months:

JACOBSEN, LYDIK, R. L. EVALDSON AND R. S. AYRE: Response of an Elastically Non-Linear System to Transient Disturbances.

MOON, PARRY AND DOMINA EBERLE SPENCER: A Modern Approach to Dimensions.

FANO, ROBERT M.: Theoretical Limitations on the Broadband Matching of Arbitrary Impedances.

FANO, ROBERT M.: A Note on the Solution of Certain Approximation Problems in Network Synthesis.
SILBERSTEIN, LUDVIK: Developable and Developed Silver Halide Grains.
MINIAMIOZI, K. AND H. OKUBO: A Note on the Notch Effect of Metals.
ROOP, WENDELL P.: The Part of Octahedral Theory in the Study of the Plasticity of Metals.
LEITNER, A., AND R. D. SPENCE: The Oblate Spheroidal Wave Functions.

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BARTOL RESEARCH FOUNDATION

Abstract of* The Detection of Heavy Particles in the Primary Cosmic Radiation.—M. A. POMERANTZ[1] AND F. L. HEREFORD.[1] A new technique, involving a coincidence train of Geiger-Mueller counters filled at low pressure, has revealed the presence of heavy nuclei in the primary cosmic radiation. The method exploits the dependence of the probability of discharge of a Geiger-Mueller counter upon the nature of the gas filling and renders it feasible to resolve the various components of cosmic radiation. By comparing results obtained under different conditions, it has been determined that the primary radiation at 52° N consists approximately of two-thirds proton, one-third α-particles, and a small amount of heavier nuclei. The experiments are still in progress and should lead ultimately to a complete quantitative resolution of the cosmic radiation throughout the atmosphere.

* Letter to the Editor in the *Physical Review*, October 1, 1949.

[1] Physicist, Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

Abstract of* Summary of Bartol Cathode Work.—W. E. DANFORTH.[1] The Bartol program, sponsored by the Bureau of Ships, consists in the carrying out of such investigations concerning thoria and similar cathode materials as are pertinent to magnetron development. Thermionic emission, pulsed and d-c., is continually being studied. One objective, among others, is to establish the picture regarding emission activation, a matter which has primary importance in the temperature region below 1500° C. Composite results for well-activated cathodes from several laboratories are in fair agreement with a Richardson curve in which $A = 0.33$ and $\varphi = 2.0$.

Direct current from thoria is limited to approximately 5 amp./cm.^{2} by decay, and investigations of this subject are continuing. No short time decay of 10^{-6} sec. time constant, as often observed with BaSr oxide, is present, the smallest time constant being some tenths of one second, a fact which recommends thoria for long pulse applications.

Rates of evaporation, and of disappearance of the material with passage of current, have been measured and the observations are continuing. On the basis of evaporation alone a coating of 1 mil thickness will completely evaporate in 350 hr. at 1800° C. (true), a temperature where the primary thermionic emission is 14 amp./cm.^{2} At 1650° true temperature, where the primary emission is about 5 amp./cm.^{2}, the evaporation life is 4000 hr. per mil thickness. The passage of high d.c. accelerates the disappearance, preliminary results indicating that for coatings the passage of 1 amp./cm.^{2} decreases the life by a factor of 2, a figure which is roughly independent of temperature.

Studies of electrical conductivity of sintered thoria at high temperatures and high vacua are being pursued. Present results are confined to moderate vacua of about $0.5\text{–}1 \times 10^{-5}$. Activation phenomena occur. A resistance as low as 20 ohm-cm. at 1000° C. has been obtained by high current activation. A sealed-off and gettered vacuum furnace for these studies has been built and preliminary tests are being made.

Thermionic emission studies have been made with thoria plus numerous admixtures, none of which, to date, has increased its emission. Studies have also been made with coated cathodes of ZrC, TaB, TaC, and TiC, among which ZrC is the most interesting, its emission exceeding that of thoria in the temperature region below about 1400° C.

A 10-cm. high powered pulsed magnetron, with a structure permitting cathode replacement, is being developed.

Abstract of* Zirconium Carbide as a Thermionic Emitter.—R. E. HADDAD,[1] D. L. GOLDWATER,[1] AND F. H. MORGAN.[1] The thermionic emitting properties of zirconium carbide (one of several materials under investigation) are reported. Values obtained are

$$A = 0.2\text{–}0.5 \text{ amp./deg. k}^2\text{cm.}^2$$
$$= 2.1 \text{ (6) volts.}$$

For the Richardson equation

$$I_s = AT^2e^{-b/T},$$
$$b = 11{,}605.$$

At 1500° C$_b$, stable emission of 0.6 amp./cm.^{2}, d.c. is obtained. At 1700° C$_b$, 6 amp./cm.^{2} currents are obtained with microsecond pulses.

The spectral emissivity of ZrC has been obtained, and is essential to interpreting pyrometer readings. The value obtained is 0.96 ± 0.04.

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* Paper given at ONR Conference in Washington, D.C., August 8, 1949.

[1] Assistant Director, Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

* Letter to the Editor appearing in the *Journal of Applied Physics*, September, 1949.

[1] Junior Chemist, Electrical Engineer and Junior Physicist, respectively, Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

APPLICATION OF A SEMI-QUANTITATIVE ESTIMATION OF NITROGEN AND OTHER ELEMENTS IN ORGANIC MICROANALYSIS*

BY

WILLIAM G. BATT

When organic nitrogen samples are brought into the microchemical laboratory at least one of the following analyses is required: (1) qualitative; (2) semi-quantitative, whereby an approximation is arrived at rather quickly; (3) quantitative, whereby the amount of nitrogen is determined to the decimal point.

The qualitative determination of the presence or absence of nitrogen, sulfur, and the halogens is an important step in the identification of an unknown substance. Not only is this information useful in itself but other steps in the identification procedure depend upon it. This step is essential when dealing with unknown samples, for it is wasted effort to spend probably an hour on a quantitative determination when a simple screening test may eliminate additional work by proving the absence of nitrogen. Among the methods mostly used for the elementary detection are those developed by Lassaigne, using molten sodium; Castellana, using magnesium and potassium carbonate; and Emich using lime and copper powder.

When nitrogen is present it is not always expedient to run an analysis by Kjeldahl's method, because not all nitrogenous compounds are easily broken down, for example, the pyrimidines and nitro compounds, and because the ultimate analysis by Dumas' method requires nearly an hour. Analysis by ter Meulen's method of the hydrogenation of nitrogen compounds with a catalyst (nickel) requires a high degree of experience.

A semi-quantitative method makes it possible not only to determine the approximate amount of nitrogen present, which may be all the information required, but it also serves the purpose of enabling the analyst to estimate better the amount of sample that should be used if and when a fully quantitative result is necessary.

The practical value of semi-quantitative estimation in inorganic chemistry has been emphasized by Benedetti-Pichler (5) and Swift (9) but apparently no one heretofore has applied this technique to organic elementary analysis.

In some types of control work and in synthetic organic procedures, a rapid method is very useful in following certain reactions; and in

* Paper presented as part of the Symposium on Determination of Nitrogen in Organic Compounds. St. Louis Meeting American Chemical Society, September 6 to 10, 1948.

pharmaceutical preparations the presence of certain impurities can be ascertained and estimated by a rapid although not too accurate measurement of the nitrogen content. In the testing of biochemical products a simple approximation may be advantageous in following an extraction procedure.

The sodium fusion method seems to be favored by the majority of authors of textbooks on qualitative organic analysis. On the other hand Baker and Barkenbus (4) claim that although the sodium fusion method has been widely used, it is well known that nitrogen often escapes detection. Middleton (8) also dispenses with the use of sodium and uses instead sodium carbonate-sugar, or sodium carbonate-zinc

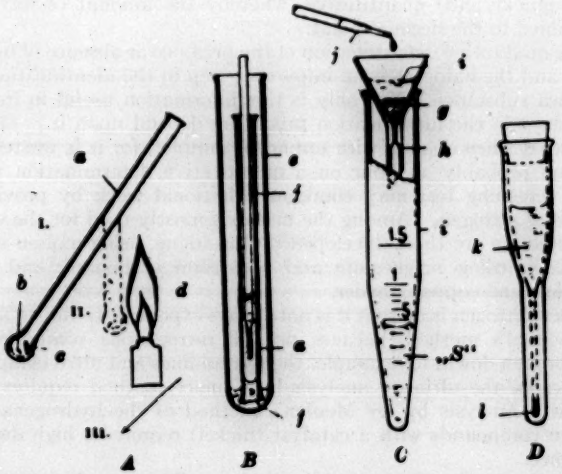

FIG. 1. Sodium fusion and semi-quantitative estimation of elements. Alber (3).

dust mixtures, and claims certain advantages of this method over the sodium procedure. Campbell (6) recently showed that a modified sodium fusion followed by detection of the cyanide ion by means of the Prussian blue test is favored for teaching inexperienced students. The advantages of this procedure have been substantiated by the number of analyses performed in this laboratory in which the sodium fusion method for elementary analysis is considered more reliable than other generally described procedures especially when other elements as well as nitrogen are to be detected. For the detection of nitrogen alone the method of Emich (7), in which air-slaked lime is used, has been found successful with as small an amount as 0.1 microgram of nitrogen. With

substances which may contain nitrogen in combination with oxygen, copper powder is added to the lime mixture.

The method to be emphasized in this paper is the one proposed by Alber (1–3), which allows the estimation to within 5 per cent (absolute) of the quantities of nitrogen, halides, sulfur, and phosphorus (arsenic) present, so that an unknown compound may be classified within a narrower range. This approximation also permits the study of the influence of interfering substances; it indicates whether one of the elements sought is present as a trace (below 1 per cent), and thus eliminates misinterpretations due to impurities, a condition which must be considered in testing biological substances.

A simple, inexpensive balance, modified according to the principle of Salvioni, may be used for the rapid weighing of samples from 0.2 to 1 mg. The sample is introduced to the bottom of a fusion tube with

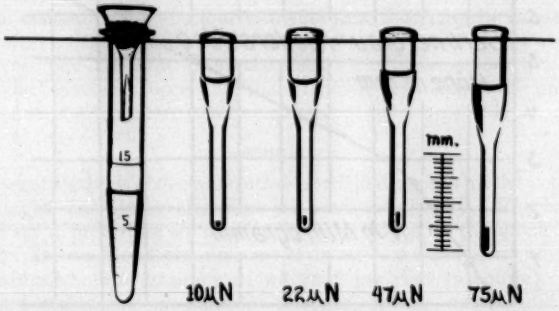

FIG. 2. Semi-quantitative estimation of nitrogen as Prussian blue precipitate.

two bulbs, both of which contain metallic sodium. By heating the upper bulb first, even liquid samples will be decomposed without loss, since the vapors have to pass the hot sodium. The heated mass is dissolved in water, with the usual precautions, and the soluble material is allowed to be thoroughly leached out by boiling slightly. The filtrate is separated from the insoluble material by passing through a Strzyzowski funnel, with asbestos as a filtering medium, and centrifuged by means of a hand model. The filtrate is then brought to a definite volume in a calibrated microcentrifuge cone. Aliquot portions of this slightly alkaline stock solution are used for subsequent tests. The individual tests are performed in straight-tip cones as used by Benedetti-Pichler and Spikes.

The test for nitrogen is made by the usual method of adding ferrous sulfate solution, mixing well and then acidifying with H_2SO_4. No particular advantage has been observed by adding a small amount of

potassium fluoride as recommended by Viehoever and Johns (10). The precipitate of Prussian blue is concentrated in the stem of the cone by hand centrifuging a definite number of revolutions or a prescribed length of time and compared with a standard compound which has been treated in a similar manner. The height of precipitate in the straight tip cone gives an approximation of the nitrogen present in the original sample. If the N to C ratio is high it may be found advisable to mix the compound with an equal weight of powdered sugar before the sodium decomposition and the fusing of this mixture with the molten metal will often assist in converting the nitrogen to sodium cyanide.

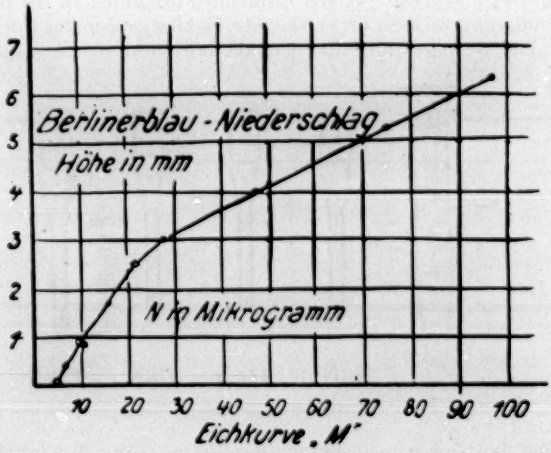

FIG. 3. Working curve for estimation of nitrogen content. Alber (3).

Sulfur may be estimated by acidifying the stock solution with acetic acid and adding a few drops of lead acetate solution. The black precipitate of lead sulfide is centrifuged in the previously described manner and compared with a standard. If a test of the stock solution in dilute HCl with ferric chloride solution produced a blood-red color the presence of thiocyanate is indicated. This is suggestive of insufficient sodium being used in the original fusion. Sodium thiocyanate first formed is frequently decomposed by excess metallic sodium into sodium cyanide and sodium sulfide.

The halides may be approximated by acidifying an aliquot portion of the stock solution with concentrated nitric acid and boiling gently for a few minutes to expel any hydrogen cyanide or hydrogen sulfide which may be present. A few drops of silver nitrate solution are then

added, and the solution again boiled to destroy any silver thiocyanate which may be present when both nitrogen and sulfur are found in the original compound. A heavy precipitate indicates the presence of chlorine, bromine, or iodine. If only a faint turbidity or opalescence is produced it is probably due to the presence of impurities in the reagents or in the glass of the tube used in the original decomposition. The differentiation and separation of chlorine, bromine, and iodine, which are present as silver halides after the estimation, are made possible by the differences in their solubilities in ammonium carbonate and ammonia, provided the ratio of the elements is approximately 1:1:1.

Phosphorus may be estimated by boiling a portion of the stock solution with concentrated nitric acid. The solution is cooled to about 60° C. and ammonium molybdate reagent added. The crystalline precipitate of ammonium phosphomolybdate (ammonium molybdiphosphate) is measured and compared with a known sample.

The estimations of the four elements described may be carried out easily after a little practice, and the time consumed will, on the average, not exceed one-half hour for all the tests. The information obtained is more conclusive and supporting than the mere reporting of the presence or absence of nitrogen or other elements.

SUMMARY

Several methods of decomposition of original sample for the detection of nitrogen and other elements are reviewed briefly. Emphasis is placed on a procedure in which aliquot portions of the stock fusion solution are used and the amount of constituent elements present is approximated. An accuracy of within 5 per cent (absolute) can be obtained within half an hour for nitrogen, halides, sulfur, and phosphorus. The method is useful as a screening test, and allows the selection of the correct amount of sample for a quantitative organic microanalysis.

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BOOK REVIEWS

INTRODUCTION TO RADIOCHEMISTRY, by G. Friedlander and J. W. Kennedy. 412 pages, illustrations, 14 × 21 cm. New York, John Wiley and Sons, Inc., 1949. Price, $5.00.

This book, written as a text for a college or graduate course in radiochemistry, is the first of its kind to appear and is certain to meet with a most cordial welcome. One of the most striking features is the large variety of topics discussed, some in brief and some in detail, and although many of them seem far afield from the subject of radiochemistry, the order and mode of presentation are such as to bring them neatly together into a logical picture of this extremely important branch of science. Included in the book are chapters on nuclear structure and properties, on high-energy particle accelerators and nuclear chain reactors, on the interactions of radiations with matter, on instruments for radioactivity measurements, on statistics of radioactivity measurements, and on the study of nuclear radiations, all in addition to chapters on the actual application of radioactivity to chemistry. In my opinion, one objection to the book is the relative lack of material on the subject of radiochemical techniques and procedures. Presumably this subject is to be treated in detail in a forthcoming reference book entitled "Radioactivity Applied to Chemistry," edited by Professor A. C. Wahl of Washington University, and one may hope that this companion volume to an "Introduction to Radiochemistry" will soon be published.

The problems, which are included at the end of each chapter, are well-chosen and do much to complete the understanding of the text. The references cited do not constitute a complete bibliography but rather serve as an introduction to the recent literature and to the standard reference works.

Both Friedlander and Kennedy have wide experience as radiochemists and as teachers of radiochemistry and they have put into their book many features which will make it a useful reference for anyone working with radioactive materials. They are to be commended for the excellent job they have done in assembling such a well-written text.

E. SHAPIRO

FROM EUCLID TO EDDINGTON, by Edmund Whittaker. 212 pages, 14 × 23 cm. Cambridge, University Press, 1949. Price, $4.00.

About three centuries before the beginning of the Christian era through a sustained effort by the early Greeks, a new revolutionary concept concerning the properties of space was enunciated. These early geometers building on the quicksands of their immediate knowledge began the development of scientific philosophy which culminated in the exposition of the theory of relativity early in the 20th century.

Between Euclid and Eddington there lived many expounders of natural philosophy whose names have become cornerstones in the Physics structure today. Scientist philosophers like Descartes, Kepler, Newton, Leibnitz, Kant, Einstein, and others flashed comet-like across the horizon leaving trails, or threads, tying together the building blocks of our knowledge. These giants were to be followed by still another intuitive genius, Sir Arthur Eddington, who undertook the monumental task of unifying philosophical thought and correlating the laws of nature from the macrocosmos to the microcosmos.

In "From Euclid to Eddington" Sir Edmund Whittaker has digested the history and development of scientific philosophy in a remarkably skillful and succinct manner and at the same time he has "disengaged the essential ideas from the intricacy of mathematical presentation." He has taken the philosophers of the past and present and filed them into niches which expose their contributions to the science. He has further shown how, with an almost mystical insight, Eddington has arrived at abstract numbers which linked the domain of the atoms and the universe. He has succeeded in taking a complex, difficult subject and with uncanny facility translating it into readable form. The reviewer finds a close analogy between

this book and "Stars and Atoms" by Eddington. "Stars and Atoms" is essentially a non-mathematical digest of portions of "The Internal Constitution of the Stars" and as such is a readable and delightfully pleasant book. Sir Edmund has in a way accomplished this feat in his book.

The history and development of scientific philosophy is a history of the evolution of concepts and principles. These concepts change and with their change results scientific progress. Man, being what he is, cannot stagnate, his thought processes cannot become static and because of this, new ideas, new concepts, new principles will appear on the horizon to relegate the present ones to the past. In this book the author has tried to bring the reader up-to-date in this revolution by a penetrating analysis of the profound changes which have taken place in our thinking even to the controversial concepts now under discussion.

Of especial and immediate interest is the imminent work of the 200-in. telescope. It may be safely assumed that within the next ten years many answers to controversial questions such as the red shift, the expanding universe, the size and structure of the universe may be obtained and it is to be regretted that Eddington is no longer alive to see whether his pioneering concepts in the new philosophy will be discarded, altered, or will prove a powerful influence to mould the course of natural philosophy in the future. The next few years should mark a new era in the history of natural philosophy and "From Euclid to Eddington" will go a long way in grounding one in the essentials to understand the changes which will inevitably take place in our thought and reasoning.

I. M. LEVITT

ENGINEERING DEVELOPMENTS IN THE GASEOUS DIFFUSION PROCESS, by Manson Benedict and Clarke Williams. 129 pages, illustrations, 16 × 23 cm. New York, McGraw-Hill Book Co., 1949. Price, $1.25.

As the annals of the atomic bomb are slowly presented in the form of the Manhattan Project Section of the National Nuclear Energy Series, a significantly larger, but still small, fraction of the public will become aware of the vast number of years of work which were crowded into the three actually involved. The declassifiable material available for the series will probably occupy 60 volumes, of which the above-titled is one of the first few published.

This book describes a few of the important engineering techniques born of the complications entailed in separating U^{235} in the form of corrosive uranium hexafluoride (UF_6). Since the UF_6, mixed with other gases, was diffused through porous membranes at definite pressures, instrumentation was required, after obtaining vacuum tight apparatus, to follow the pressure and percentage composition, and perform various other operations. The descriptions of the nine devices presented were apparently written by the inventors and edited by Benedict and Williams.

Continuous process-gas analysis was accomplished by means of recording mass spectrometers and ionization chambers. The former was used for analyses of all the components of the gas streams containing 0.1 per cent to 100 per cent UF_6, while the latter determined UF_6 present in quantities of 0.1 per cent to 1×10^{-4} as a function of the radioactivity of the three uranium isotopes. These instruments are described with the aid of schematic diagrams.

A "magnetic gear for torque transfer to a closed system" is discussed briefly and none too clearly.

One of the greatest engineering achievements of the diffusion process was the construction of thousands of vacuum tight diffuser units, necessitating a tremendous and immediate advance in vacuum pressure testing and leak-detecting. For this purpose, the mass spectrometer calibrated for helium detection, was most successfully applied. When helium was directed at suspicious points of the evacuated apparatus, the spectrometer quickly announced the entrance of the foreign gas. The instrument itself, together with related plant problems and specifications, are presented in two chapters.

Other sections include papers on UF_6 cold traps, absorption of UF_6 in oil and continuous fluorine disposal apparatus.

It is hoped that later books in this series will present further data and more complete descriptions of these and other engineering aspects of the diffusion process, which can provide

many pages of thrilling material. And in any case, the series will indicate experimentally the high probability that exists for science's solving critical problems such as cancer if given the proper material backing.

ALBERT L. MYERSON

PHILOSOPHY OF MATHEMATICS AND NATURAL SCIENCE, by Hermann Weyl. 311 pages, 15 × 23 cm. Princeton, Princeton University Press, 1949. Price, $5.00.

A large portion of this book is a translation of an article written in 1926 and published in 1927 under the title "Philosophie der Mathematik und Naturwissenshaft," appearing in R. Oldenbourg's *Handbuch der Philosophie*. The book has been brought up-to-date by a number of minor alterations, the inclusion of references to recent publications, and the addition in six appendices of brief essays based on recent developments in mathematics, physics, chemistry and biology, the latter having been excluded from the original work principally because of another specialized article in the same publication.

As indicated by the circumstances attending its original preparation, the book is concerned as much with the historical as with the systematic aspects of scientific philosophy. In his preface the author states that "one of the principal tasks of the book should be to serve as a critical guide to the literature listed in the references," much of which, as well as parts of the critical guide itself, will require a certain amount of preparation on the part of the reader.

Part One, Mathematics, discusses Mathematical Logic, Number, and Geometry; and Part Two, Natural Science, is concerned with Space and Time, Methodology, and The Physical Picture of the World, all from the point of view of the philosophically-minded mathematician and scientist. Ideas and concepts made definite by modern experimental science are compared with those of earlier philosophers and natural scientists. In the course of the discussion, the line of thought covers a wide range. It is intriguing, for example, to find in a single sentence, and presented in a single connection, references to Albert Schweitzer, Coleridge, and St. Anthony's sermon to the fishes.

Essays in the appendix, based on recent scientific work, include The Structure of Mathematics; *Ars Combinatoria* (with applications to biology and genetics as well as the other sciences); Quantum Physics and Causality; Chemical Valence; Physics and Biology; and finally Morphe and Evolution, with references to Bergson, Shaw's "Methuselah," H. F. Osborn, P. Jordan, Julian Huxley, and the Bible included in the closing paragraphs.

In the concluding sentences of Part Two, the author presents the following summary: "Exact natural science, if not the most important, is the most distinctive feature of our culture in comparison to other cultures. Philosophy has the task to understand this feature in its peculiarity and singularity. The ideas presented here . . . should be looked upon as endeavors toward this end—although I cannot but admit that the task is at present far from being completely accomplished."

C. T. CHASE

SKYSHOOTING, by R. Newton Mayall and Margaret Mayall. 174 pages, illustrations, and plates, 16 × 24 cm. New York, Ronald Press Co., 1949. Price, $3.75.

Many, many times in the observatory of The Franklin Institute the reviewer has been asked the question, "How do I take a photograph of the moon, the sun, or of the stars?" After the question there came the involved answer—dealing not only with the question but also the inquirer's ability as a photographer. Now along comes a book with the completely modest title of "Skyshooting" which answers all the questions one can raise regarding celestial photography.

The Mayalls have written a wholly intelligible book containing all the essentials necessary for the taking of sky pictures. This reviewer has been through the entire routine. He spent six years photographing the sun each clear day at the Cook Observatory. He has used the 10-in. astrographic and the 28-in. reflector at the same Observatory. He has taken planet pictures with the 10-in. Zeiss refractor and has photographed the moon in and out of eclipse with the 24-in. reflector of The Franklin Institute Observatory. With this as a background

he whole-heartedly endorses the book "Skyshooting." It contains all the information needed to use a camera on the sky.

There are some minor suggestions which could be offered and these not in the sense of criticism, but in hope that in a second edition these might be given serious consideration. The summary presented at the end of each chapter is an excellent digest of the content of the chapter. It would be desirable to have a single section in an appendix which would combine all this information where it may be immediately available. A listing of all the Amateur Astronomical Associations similar to the listing found in *Sky and Telescope* would be a welcome addition and more to be desired than the list of the professional observatories in the country This book may not appeal to the professional astronomer because in all probability his background includes most of the material contained in the book. This type of book will appeal to the layman who seeks a hobby or to the amateur astronomer who desires to do serious photographic work on the sky. A listing of organizations where this work may be furthered would be a valuable addition to the book.

The book is remarkably free of errors and only in one place is there any question as to the text. The authors state, ". . . the most valuable property of the photographic emulsion is its light-gathering power, ..." The word gathering is an unfortunate choice. The optical system determines the light-gathering power—a better word would have been light-storing.

The book is well written, beautifully illustrated with carefully selected amateur photographs, excellently compiled and highly recommended for the average individual who would turn his camera to the sky.

I. M. LEVITT

ELEMENTARY METALLURGY AND METALLOGRAPHY, by Arthur M. Shrager. 297 pages, tables, illustrations, 16 × 24 cm. New York, The Macmillan Company, 1949. Price, $4.75.

The increasing interest in metals and alloys used in manufacturing machines, tools, appliances and industrial products, makes it necessary for those dealing with metals to have a clear understanding and knowledge of the underlying principles and concepts of metallurgy and metallography. Many excellent books have been written as well as a vast number of technical papers on the general subject and specialized fields. However, most of these are treated on or above the engineering level. This book treats the subject matter from an elementary approach for individuals below the engineering level, requiring metallurgical training. The subject matter is presented well in a clear, concise manner which is easy to follow yet combines theory and practice in a well ordered progressive sequence, with sufficient theoretical background to afford anyone interested in the subject of metals and alloys ample opportunity to gain a useful working knowledge and understanding of the subject. The book consists of 24 chapters dealing with structure of metals, slip and plastic deformation, recrystallization, mining, ore reduction, constitutional diagrams. The structure of iron and steel in the solid state is well illustrated. The allotropic changes and transformations which take place upon heating and cooling are included. Typical constitution diagrams are shown illustrating their application and use in connection with the various processes such as heat treating. The correlation of microstructure, and physical properties with the constitution diagrams is useful.

Most metals occur in nature as ores containing a great deal of other material and must be separated and purified to be put in useful form as metals or alloys for specific purposes. The processes involved in winning metals from their ores are described, and the history of steel is covered showing how advancement in the art and science has progressed from the sword of Damascus to our present alloy steels used for highly stressed parts. The function and use of alloying elements together with laboratory methods of control are described briefly. The principles underlying heat treatment, working and fabricating metals are covered including the more recently developed isothermal transformation diagrams, hardenability tests, Austempering, Martempering, induction hardening, and surface hardening. The mechanical properties can be altered by suitable alloying, working and heat treatment resulting in more satisfactory performance of steel parts for industrial use.

Chapters covering copper, aluminum, magnesium, and zinc together with typical alloys and properties are included. Useful tables are included as well as an excellent glossary of metallurgical terms.

This book should prove useful to a large number of individuals working with or dealing with metals and alloys. Presented in such a clear, concise manner, it fills a real need in the metals industries for sound information about metals.

STUART S. KINGSBURY

STRENGTH OF MATERIALS, by Gerner I. Olsen. 442 pages, illustrations, 16 × 24 cm. New York, Prentice-Hall, 1949. Price, $4.25.

Another book has been added to the already long list of books on the subject of strength of materials. However, this differs from most of the others in the method of approach to the various subjects. As the author indicates in the preface, the book is for use in technical institutes, college extension courses, trade schools and colleges where the subject is presented without the prerequisite of calculus. Consequently, the material is presented very simply and directly, requiring no more mathematics than algebra. Refreshingly, too, the author emphasizes the practical use of the material. Unfortunately, the scope of the various subjects treated is somewhat limited, but then it isn't written for the advanced student.

The book contains the usual strength of materials subject matter. The initial three chapters discuss the principles of mechanics and fundamental stress and strain relationships. Then follow chapters on thin-walled cylinders and spheres and riveted and welded joints, torsion, shear and bending moment diagrams, design and deflection of beams, statically indeterminate beams, stresses due to eccentrically applied loads, columns, combined stresses, and fatigue strength and stress concentrations. Excellent illustrations throughout the volume aid greatly in the explanation of various concepts. Sometimes it is difficult to "see" forces or stresses in three-, or even two-, dimensional objects; the student should have little or no such difficulty upon studying this book. Examples are used frequently to explain theories, and each chapter contains problems whose solution will aid further in the understanding of the strength of materials.

E. W. HAMMER, JR.

COMMUNICATION CIRCUITS, by Lawrence A. Ware and Henry R. Reed. Third edition, 403 pages, illustrations, plates, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1949. Price, $5.00.

Having used the first and second editions of this book for classroom instruction, this reviewer finds the present third edition a welcome addition to that group of textbooks especially written for communications engineering students taking a first course in this subject. It is presupposed that the reader has a knowledge of calculus and a-c. theory. Sufficient vector and electromagnetic theory to develop Maxwell's equations in forms useful to the modern communications engineer is included in an appendix, as are the elements of Bessell functions.

The elements of transmission circuits are common to many branches of electrical engineering. A first chapter, completely rewritten from the earlier editions, treats of wire transmission line parameters, their physical interpretation and means of computation for the entire frequency range of interest. The ideas of shunt conductance and capacitance lead to the development of the short line with lumped constants and the standard transformations for T and π sections.

In a clearly written style the authors carry the reader through the basic ideas of characteristic impedance, propagation constants, and distortion, first for the line composed of finite sections; then the corresponding theory is developed for the line having uniformly distributed parameters. These concepts are finally used to consider the transmission line which is terminated first in its characteristic impedance resulting in unidirectional propagation, then in a general terminating impedance which causes reflections. The open and short circuited line are given the usual "special consideration" because of the importance of these cases in line tuning. Questions of line matching and impedance transformations are treated separately because of their importance.

As a natural development from the frequency dependency of T and π sections, consideration is given to the fundamental properties of reactive networks, which serve as a basis for the design of the common varieties of constant-K and M-derived filters.

Circular and cylindrical wave guides and coaxial cable are today commonly used transmission means. An elementary but thorough treatment of introductory problems is included in this edition. These subjects are treated by field theory based upon Maxwell's equations with appropriate boundary conditions. One chapter is devoted to each of the major transmission means noted above, each time starting with the basic differential equations to derive the important parameters. One chapter is devoted to an outline of twelve transmission line experiments which illustrate basic principles.

This volume should find the same wide acceptance in educational circles as did the earlier editions. The illustrative examples worked out in the text help the reader grasp the principles presented and the rather complete set of problems, many of them new in this edition, are sufficient in number to keep any student busy for quite some time. Practicing electrical engineers who wish a quick review of some basic communications engineering would do well to read this book in their leisure moments.

S. CHARP

ATOMIC ENERGY LEVELS, Vol. I, ^{1}H–^{23}V. National Bureau of Standards Circular 467. 309 pages, 24 × 30 cm. Washington, National Bureau of Standards, 1949. Price, $2.75.

A critically evaluated compilation of all known data on the energy levels of elements of atomic number 1 through 23 has recently been published by the National Bureau of Standards and is now available from the U. S. Government Printing Office. Designed to meet the needs of workers in nuclear and atomic physics, astrophysics, chemistry, and industry, the publication is an up-to-date compendium of all energy levels for these elements exclusive of those due to the hyperfine structure ascribed to atomic nuclei.

The present volume is the first of a series being prepared at the Bureau as part of a general program on atomic energy levels derived from observations of the optical spectra of atoms and ions. Section 1 of this volume (hydrogen through fluorine) has previously been published separately. The new series represents the cooperative effort of scientists throughout the world and will constitute the first compilation of atomic energy levels in the last 18 years, during which time the number of known energy levels has increased by a factor of 4 or 5.

In this series, spectra are presented in order of increasing atomic number, and under a given atomic number they are listed in order of increasing stages of ionization. For each spectrum a selected bibliography covering the analysis is given. The energy levels are tabulated in the related groups that form spectroscopic terms, counting upward from the lowest as zero. Electron configurations are also given in the tables, together with term intervals, Lande g-values, and term designations in a uniform notation. For the more complex spectra arrays of observed terms and their electron configurations are included. Similar arrays of the terms predicted by theory for important isoelectronic sequences are given in the introduction.

Volume 1 (containing Sections 1–3) of the National Bureau of Standards Circular 467, entitled *Atomic Energy Levels*, by Charlotte E. Moore, 352 large 2-column pages, cloth-bound, can be obtained from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at a cost of $2.75 a copy. Remittances from foreign countries must be in U. S. exchange and must include an additional sum of one-third the publication price to cover mailing costs.

ERRATUM: "Photoelectricity and Its Applications," by V. K. Zworykin and E. G. Ramberg, reviewed on p. 267, Vol. 248, of this JOURNAL, was erroneously listed as "Photoelasticity and Its Applications."

BOOK NOTES

TECHNICAL DRAWING, by Frederick Giesecke, Alva Mitchell and Henry Cecil Spencer. Third edition, 851 pages, illustrations, 16 × 24 cm. New York, The Macmillan Co., 1949. Price, $4.50.

This standard textbook on engineering drawing has been considerably revised and amplified in the present edition. The chapters on Fasteners, Shop Processes and Aeronautical Drafting are among those which show extensive revision. In addition to including over one hundred new illustrations, many of the old ones have been redrawn to make them clearer. The text throughout has been brought into accordance with the 1946 revision of "American Standard Drawings and Drafting Room Practice." The material contained in the appendix adds much to the reference features of the work.

BIBLIOGRAPHY OF RESEARCH ON HEAVY HYDROGEN COMPOUNDS, compiled by Alice H. Kimball and edited by Harold C. Urey and I. Kirshenbaum. 350 pages, 15 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1949. Price, $3.25.

This volume of the National Nuclear Energy Series presents a listing of nearly two thousand references on heavy hydrogen and its compounds. The list is alphabetical, arranged with cross references from variant spellings of names and co-authors. A code system has been established to indicate the general scope of each article. A subject index arranged by these code symbols is included indicating the articles coded under each classification. In addition, there is an index by compounds, subdivided by the code symbols.

The list was compiled primarily from *Chemical Abstracts* 1932 to 1945, with additions from other sources. A useful feature is the inclusion of the *Chemical Abstracts* citation in nearly all cases. With its various aids, the bibliography will serve a number of purposes and should prove valuable for anyone concerned with the early work on deuterium.

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TV PICTURE PROJECTION AND ENLARGEMENT, by Allan Lytel. 179 pages, illustrations, 14 × 22 cm. New York, John F. Rider Publisher, Inc., 1949. Price, $3.30.

This book offers a presentation of the basic optical principles involved in television picture projection, with a description of the different methods employed. Particular attention is paid to the commercial applications of the modified Schmidt and the refractive projection systems. Suggestions are made as to adjustments. Brief consideration is given to newer systems and possible developments in television projection. The work should prove useful for both the serviceman and the student.

CURRENT TOPICS

Aerocar Prototype to Begin Flight Tests This Month (*American Aviation*, Sept. 15, 1949).—A new development in the roadable airplane field is scheduled to unfold this month at Longview, Wash., where the Aerocar prototype is slated to begin flight tests.

Officials of Aerocar, Inc., report that to date the auto portion of the craft has traveled about 1000 miles; that driving it is routine—except for the problem of handling the crowds of people whenever it's parked in town.

Tests have shown the mileage to be 28 miles to the gallon, equal to the best performing automobiles in the light auto bracket. The craft attained speeds of about 60 on the highway with best performance determined at about 45 miles an hour. On a sod surface runway it accelerated to 75 mph. in 900 ft., plenty of speed for a take-off run. It appears that the Aerocar can perform about like a Crosley or an Austin on the highway.

The early-scheduled flight tests should go smoothly, say the engineers, since wind tunnel tests in 1948 indicated that design characteristics were satisfactory. Tests were run off at the University of Washington with a one-fourth scale model which preceded the development of the prototype. In the wind tunnel the model indicated the design competed favorably with that of conventional lightplanes.

The prototype incorporates the spin-proof, two-control feature and full provision for cross wind landings, with one steering gear for operation in the air and on the highway. It has front wheel drive from a 100 hp. Franklin engine which furnishes power for the more or less conventional prop at the tail of the flight component. The shaft to the prop was one of the most troublesome design problems, but officials say it has been solved to their satisfaction and to the "fair satisfaction," so far, of CAA. Full throttle operation of the drive shaft under stringent conditions showed that it should prove satisfactory in the air. Engineers expect top speed in the air to be about 109 mph., normal cruise about 100. Rate of climb should be over 500 fpm. and service ceiling 12,000 ft. Cruising range should be "about 300 miles;" it should land at 53 mph. with flaps in 300 ft. to full stop. It should take off and clear a 50 ft. obstacle in 1250 ft. Fuel consumption is estimated at 6 gal./hr. in the air.

The Aerocar has all of the equipment needed to meet state vehicle laws for operation on the highway. Four wheel brakes, three speeds forward, one in reverse are controlled with conventional foot pedals and gear shift. Excellent ground stability is designed into the auto component built entirely of metal, employing separate keel box structure. Hydraulic shock suspension ride control and roll-down windows should insure comfortable riding on the highway.

Fort Benning Housing Project Uses TECO Trussed Rafters.—Battle Park Homes, Inc., the Army's new 200-unit housing project for service personnel near Fort Benning, Georgia, may well serve as an economical prototype for the long-range plans of the National Military Establishment to alleviate the short-

age of quarters in all branches of the service, says Homer Maxwell of Maxwell and Hitchcock, Atlanta, who have worked closely with the designers and builders in effecting new economies in the project.

When completed, Battle Park Homes will make available 88 modern 4½ room and 112 5½ room residences for service families stationed at the big Georgia base. James W. Biggers and Associates, Columbus, Georgia were the architects for the project, which is being built by the Jordan Construction Company.

Expansion and improvement in quarters at bases in all branches of the service has long been sought by the various departments. The Army alone estimates its needs at 150,000 new units in the next few years. Many service families have been occupying quarters which were built as temporary structures during the first World War. It now appears that, coincidental with the passage of the new general housing bill, military families will also find relief through Congressional authorization for extensive construction of multi-family rental units at scores of posts.

The new Fort Benning units are high-efficiency, low-cost buildings, says Maxwell. They are F.H.A. Type 608 built with a wood frame covered with brick veneer on concrete slabs. In addition to the low-cost wood frame an important new economy has been added in the form of fabricated trussed rafters joined with split ring connectors. The new rafters cut roof framing material about 25 per cent over conventional methods and reduce labor accordingly.

Maxwell explains that the trussed rafters, based on designs developed by the Timber Engineering Company, Washington, D. C., are simple four-member assemblies composed of standard 2×4 and 2×6 lumber. Extra strength gained through the use of the timber connectors reduces the size of the lumber required to do the job and permits the trusses to be spaced 24 in. on centers rather than the usual 16 in. used with ordinary rafters.

The new system which has already been used in nearly 20,000 units in privately built garden type apartments, does away with the need for bearing partitions and thus saves labor on most interior mechanical operations. Trusses are usually built on the job by the contractor through a simple fabrication system employing common labor. The rafters are spaced and held in place by another new development—TRIP-L-GRIP framing anchors, easily installed lightweight metal clips providing reliable ties between roof and walls.

Three other new Georgia projects, the Poole Creek Apartments, Atlanta, the University Court Apartments, Athens, and a housing project of the Mangham-Butler Company in Atlanta, have also adopted the new roof framing system.

Cortisone Research.—The necessity for providing financial support for further clinical research on cortical and related hormones was highlighted recently at the Cortisone Conference sponsored by Research Corporation.

Dr. Robert R. Williams, director of grants for Research Corporation, outlined for key scientists and representatives of private foundations and government services three steps that had been taken to speed the vital research on the hormone which has been widely heralded for its promise in treatment of rheumatoid arthritis, rheumatic fever and other diseases:

1. An agreement is about to be effected with owners of patents on many of the 30-odd steps in the present method of producing cortisone whereby each will be free to use the patents of the others. Research Corporation will also be free to license other firms under any of the patents. This is regarded as an important step in assuring future production of cortical hormones for public use.

2. Research Corporation and Merck & Co., Inc., present sole producer of cortisone, have agreed to abide by the decisions of the committee appointed by the National Academy of Sciences to allocate the currently meager supply of cortisone. This agreement assures that the quantities of the hormone available in the next few months will be employed only for experimental use by qualified scientists whose requests are approved by the National Academy.

3. In addition to grants of some $50,000 made since 1941 to Dr. Kendall of Mayo Clinic, discoverer of cortisone, Research Corporation is contributing about $85,000 this year in grants to scientists in American academic institutions who may be able to contribute better synthetic approaches to cortisone and related substances.

Pointing out the immediate need for additional research funds, Dr. Williams declared, "The entire output of bile acids (present raw material for cortisone) from our slaughter houses will not make enough cortisone to provide continuous treatment for more than one-tenth of one per cent of all the arthritics in this country, should such treatment prove necessary or desirable.

"The remedy is not to be found in minor improvements of present process. A synthesis must be developed either from simple artificial substances or from some much more abundant natural material. Either will require extended research, but important clues to processes on other raw materials exist and are being explored."

Enormous Coal Reserves of Montana Appraised.—Coal reserves in Montana of 221,779,000,000 tons in place recently appraised by the U. S. Geological Survey constitute an assured and abundant source of fuel that will be available when needed to supply synthetic fuel plants, Director W. E. Wrather announced. More than 28,000,000,000 tons of lignite and sub-bituminous coal, or about 12 per cent of the total reserve is known to be present in beds 10 feet or more thick, lying under less than 2000 feet of overburden, and less than 2 miles horizontally from the outcrop.

The new appraisal is the first of a series of state summary studies being undertaken by the Geological Survey as part of a program to reappraise the coal reserves of the United States. During the period since 1928, when the last coal reserve estimate for the United States was prepared, much new work has been done by the Geological Survey and State agencies on the thickness and distribution of coal. Similarly, new estimates have been prepared for several eastern states, and for many individual mining districts. But for most States, including Montana, and for the United States as a whole, no comprehensive re-appraisal has been undertaken.

The new appraisal of Montana coal reserves was prepared in greater detail than the earlier estimates by the Geological Survey, and presents the data by counties, by rank of coal, by classes of coal according to the reliability of the

information on which the calculations were based, and by coal beds in several thickness groups. The total reserve of 221,779,000,000 tons is somewhat smaller than the earlier estimate of the Geological Survey, but the present estimate was made on a much more conservative basis, and is believed to represent a minimum figure. As new information is obtained it is expected that the estimate will be substantially increased.

Combating Cosmetic Allergy (*Manufacturing Chemist*, Vol. XX, No. 8).—However strictly a cosmetic manufacturer controls the processing of his products he must always reckon on the mischance of his lipstick or face powder being used by a person allergic to one or other of the ingredients. Unless the person is aware of her idiosyncrasy and seeks medical help the chance is she will blame the product in question and tell her friends, to the detriment of the product. The point is, assuming medical advice is sought, is it always at hand? That doctors are not always properly informed is indicated by a note in the "Any Questions" section of a recent issue of the *British Medical Journal*. The questioner asked if anything was known about allergy to lipsticks and quoted a case of a patient coming to him with raw patches and swelling of the lips occurring some two hours after using a lipstick. The answer explains that such a condition may be due to hypersensitiveness not only to eosin—the most frequent cause—but also to the perfume or fatty base used. It is also stated that there may be a superadded factor of induced light-sensitiveness owing to the fact that eosin is fluorescent. A change to a lipstick not containing eosin is recommended and the enquirer is advised to seek information from a recognized cosmetic house. It seems that in view of the prevalence of lipstick allergy manufacturers might circulate doctors with an explanatory leaflet and, where applicable, point out that a non-eosin lipstick is available. This would surely be a piece of sales promotion of great value to both manufacturer and doctor. Incidentally, it should be noted that the *B. M. J.* expert states that the application to the lips of a barrier cream, of the kind employed as a protective against industrial irritants, has been known to permit the use of a lipstick without injury.

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Portable Spray Drier (*Chemical and Engineering News*, Vol. 27, No. 38).—A unique, portable spray-drying unit of Danish design is being made available in this country through the Niro Corp.

This compact laboratory unit is particularly designed for experimental work in universities, laboratories and small scale production in pharmaceutical and industrial organizations. It may be easily wheeled from one department to another. Its performance is parallel with that of the Niro units now in use. This makes it possible to determine, on a small scale, the practicality and the technique of spray-drying various substances on a large scale.

The Niro Portable Laboratory Spray features the specially designed, high-speed atomizer head, rotating at 50,000 rpm. and ejecting the liquid product as an extremely fine mist into the drying chamber, where circulating warm air instantaneously evaporates the water content. The dry product falls to the bottom of the chamber as a fine powder, where it is funneled out as a finished, easily soluble product.

The new portable unit is constructed of stainless steel and glass, making it

suitable for conducting test runs on a wide variety of materials. The unit is equipped with both electrical and gas heating elements, and either may be used. Its capacity is 2 to 15 lb. of water evaporated per hour.

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Melamine Dinnerware Promotion (*India Rubber World*, Vol. 120, No. 6).—In order to make Melmac melamine plastic dinnerware available to the general public, the plastics department of American Cyanamid has launched a comprehensive advertising and sales promotion program designed to expand consumer markets. Melmac dinnerware has been thoroughly tested and widely accepted by restaurants, hotels, and institutions, and now a number of large molding companies will offer their lines of the product through retail stores. American Cyanamid will run a series of advertisements in consumer pubilcations, and will also cooperate extensively with the actual producers of Melmac dinnerware and with all retail outlets in sponsoring sales to consumers.

The main features of the campaign will stress that this dinnerware is a new type and style of plastic dinnerware unlike the so-called picnicware known in the past. Specifically, breakage, resistance, attractive color and design, food insulating properties, resistance to food staining, ability to withstand hot water, and similar characteristics will be pointed out to consumers.

An Electrostatic Clutch (*Discovery*, Vol. X, No. 8.—Among the exhibits which Metropolitan-Vickers Electrical Co. Ltd. showed at the fourth annual exhibition held by the Institution of Electronics in Manchester on July 19–21 was an electrostatic clutch. A polished disc of high-resistance semi-conductor and a polished metal disc, both optically flat to 10^{-4} cms., are pressed lightly together. When a potential is applied between them, a force of attraction is developed approximately proportional to the square of the potential across the discs. This effect was first observed by Johnson and Rahbek using moist lithographic stone, and ionic semi-conductor. An electronic semi-conductor, unlike lithographic stone, is not dependent on moisture content and has, therefore, been substituted in the model.

A small clutch operating on this principle was exhibited driving a dynamometer and transmitting a torque of several hundred g.cm. The power consumption of the clutch is very low.

Truck Able to Lift 110,000 lb.—A huge trailer truck and four automobiles were lifted 5 ft. from the ground by the world's largest industrial truck in a demonstration in Chicago.

The powerful truck was built for the Oldsmobile division of General Motors Corp., by the Automatic Transportation Company, 149 West 87th Street, Chicago. The show of strength took place at the Automatic factory.

Designed to lift and carry dies weighing 80,000 lb., it actually can handle loads up to 110,000 lb.

The die handling machine carries its load on a platform 93 in. long and 69 in. wide. From a starting position 26 in. off the ground, the load can be lifted to a height of 60 in.

The truck is estimated to weigh 40,000 lb., so in normal factory operation the carrier and load will total 120,000 lb. The demonstration was a mild workout requiring the lifting of a mere 15 tons.

A 72-volt battery powers the machine, enabling it to lift its massive load at the rate of 2.7 ft. per minute.

At its broadest point the truck is 85 in. wide and it has an over-all length of 184 in.

Despite the great weight involved, simple pushbutton controls guide its operation. Maneuvering dies on or off the press is a delicate task for which a winch attachment is used. This can be controlled by buttons on either side of the truck, giving the operator perfect vision.

Following the demonstration, the die handler was shipped to Lansing, Mich., where Oldsmobile's plant is located.

Designer of the record-breaking machine is Edward W. Gammell, of Automatic's engineering staff.

Automatic has been the leading producer of huge materials handling machinery since 1906. It is the producer of the Skylift Giant series of ram trucks, able to handle huge coils of steel weighing up to 30 tons. The Giants are now being used in many mills in this country and abroad.

The George Eastman House, Inc., a public educational institute to further the knowledge of photography's means, accomplishments and potentialities in every field, will be opened to the public this month.

It is fitting that the home which George Eastman built in Rochester, N. Y., should thus become an educational focus in the field which was so greatly advanced by his genius, by placing on exhibit the technological developments and the applications of photography both in the historical past and the present progress in the entire field of photography.

The institute, with facilities for exhibitions, demonstrations, lectures and the showing of moving pictures, will be a national and international center for conferences on photography; for research in its history, science and application; for the education of school children by guided tours; for meetings of camera clubs and photographic organizations, for changing exhibitions of photographic work; for demonstrations of the latest apparatus and processes; for the screening of both historical and modern motion pictures; and for other related purposes.

Such an institute should become the mecca not only of all interested in picture-making—from the specialist to the amateur snapshooter and tourist—but to the ever-increasing number of writers, magazine editors, and historians who use pictures.

Thus the purpose of the institute will be to demonstrate the technique of photography, to show the manifold part it plays in nearly every branch of human activity, and to facilitate the research of those interested in the world's most facile medium of communication.